MACROSCOPIC ANALYSIS OF WASTEWATER TREATMENT PLANTS AND ITS APPLICATION

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by

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Macroscopic Analysis of Wastewater Treatment Plants and its Application.
Thesis directed by Associate Professor Edwin R. Bennett.

The distribution of wastewater pollution parameters by total pounds mass in a wastewater treatment plant was investigated. The distribution of each parameter was used to gain further knowledge of how a treatment plant operates as an integrated unit. Utilization of this information can lead to more efficient treatment facilities. The wastewater parameters used were: biochemical oxygen demand, chemical oxygen demand, total Kjeldahl nitrogen, total phosphate, total solids, and suspended solids.

Five different treatment plants were sampled twice each while two others were sampled once. One or two hour increment grab samples were composited over a 24 hour period. The 24 hour period was assumed to be a "typical" operating day and representative of plant operation. Only weekdays were sampled, and sampling techniques and testing procedures were kept uniform to eliminate as much deviation as possible.

Results show the mass distribution of each parameter for each plant, and a parameter comparison with similar type plants. Results lead to the conclusion that a plant material balance may be a valuable analytical tool to maintain or increase plant operating efficiency. The application of this tool may, along with discrete

use of computers, upgrade the capacities and operational efficiencies of our present treatment plants.

This abstract is approved as to form and content.

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LIST OF SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS

MGD-million gallons per day

MG-million gallons

BOD_5-5 day biochemical oxygen demand

COD-chemical oxygen demand

TKN-total Kjeldahl nitrogen

$PO_4^{=}$-total orthophosphate

TS, VTS, FTS-total, volatile, fixed solids

SS, VSS, FSS-total, volatile, fixed suspended solids

mg/L-milligrams per liter

Inf.-influent

Eff.-effluent

W. A. S.-waste activated sludge

R. A. S.-return activated sludge

SYMBOLS

Parshall flume- 

Pump- 

CHAPTER I

INTRODUCTION

Wastewater treatment and reclamation of wastewaters has come to the forefront as one of our present, and probably continuing, major environmental problems. Great concern and effort is being directed towards wastewater treatment; treatment sufficient to produce a water for recycle or reuse. An article (3) in the American Water Works Assoc. Journal describes what is presently being done in Denver. In addition to reuse concepts, it is necessary to continue to build and expand wastewater treatment facilities for large metropolitan areas, for suburbs, and for separated communities in an attempt to solve pollution problems.

There will be times and places where it is just not feasible to expand or develop facilities for a small incremental demand. Bond issues or increased taxation to raise revenues may be tardy in meeting a demand for wastewater treatment plant construction or expansion. In other words, there will be times when a treatment plant will be required to operate above its designed capacity. It is believed that most treatment plants today can be operated at a higher efficiency of pollution removal.

Increased treatment capacity of existing facilities is an aspiring idea. How can such an idea become a reality? How can this task be accomplished? The proposed approach for its implementation comes in two steps. First, the operating characteristics of an existing plant must be investigated and defined to such an extent

that the integrated plant operation is well understood. Also to be understood are the ramifications of any system adjustments. Second, treatment plant operators and administrators must be informed as to what actually happens in their plants and what they can do to affect increased removal efficiencies. The point to be made here is that many operators and administrators do not have this knowledge. They cannot anticipate what would happen if they altered the systems' operation. Step two, the dispersal of information and instruction of operators and administrators, will not be covered herein. It is the purpose of this thesis to provide some of the answers on how a few specific plants may operate, and to provide the mechanism by which others can obtain the same information. Also included will be some ideas on further application of this idea.

The mechanism that will be employed in plant analysis is the material balance of a group of wastewater pollution parameters. A material balance is an attempt to balance the distribution of a pollutional parameter in a treatment plant so that the materials introduced into the system can be accounted for as they leave the system at various points. In this way an investigator can determine how much of the waste pollutant is removed or added by each unit or process within a plant. The operator may then be able to make such plant operating adjustments which would improve efficiencies in one part of the plant and not detract from overall plant performance.

The material balance has two variables: the volume of flow of a waste stream and the concentration of the specific pollutant parameter in the stream. The combination of the two variables produces the total mass of pollutant passing a point as:

Total pounds materal/day = (A)MGD x (B)ppm x 8.34#/gal.
passed a point

where 8.34#/gal. is a conversion factor. The volume of flow can be measured by devices such as Parshall flumes, Venturi meters, magnetic meters, or flow over weirs. These devices meter the flow rate over a period of time and can convert this to total flow volume. Parameter concentration analysis is usually conducted on wastewaters according to methods established in references (1) and (2).

Primary interest in plant operation has focused on the removal of biochemical oxygen demand (BOD) and suspended solids because these two parameters are widely used by state and federal agencies as pollution removal criteria. More recently, concern has been voiced about the eutrophication effects on large bodies of water due to the addition of waste nutrients such as nitrogen and phosphorus. For these reasons it was decided that the parameters to be used in the material balance analysis were:

Biochemical Oxygen Demand (BOD)
Chemical Oxygen Demand (COD)
Total Kjedahl Nitrogen (TKN)
Total Phosphates (as $PO_4^{\equiv}$)
Total Solids (TS)
Volatile Total Solids (VTS)
Fixed Total Solids (FTS)
Suspended Solids (SS)
Volatile Suspended Solids (VSS)
Fixed Suspended Solids (FSS)

Each of the above parameters is discussed individually in Chapter III.

To summarize, the main objectives of this study are:

1. to gather information about the relative distribution of wastewater pullutional parameters in specified treatment plants,

2. to provide this information to the plant operators and administrators of those plants analyzed in the survey, and
3. to see how this analytical tool may be put to beneficial use.

Objective three above opens up several possible applications for the material balance idea. A material balance can be used to optimize the removal of a single pollutant or the removal of a combination of pollutants, to minimize the cost of removal per unit mass of pollutant, and to minimize the amount of change in operation of a plant due to a continuously changing influent. These ideas will be discussed further in Chapter V.

CHAPTER II

REVIEW OF PREVIOUS RESEARCH

Background

It was believed, and confirmed after a rather thorough search of literature, that the amount of information pertaining to material balances in a treatment plant is very limited. The various journals dealing with wastewater and wastewater treatment were reviewed to see what had been accomplished in the way of defining wastewater pollutant parameter distribution in an entire treatment plant. Only a few articles of real significance could be found. These will be discussed later. Most interest or concern appeared to be directed towards the anlysis of isolated units, reactions, and processes. The investigation of the integrated system of units comprising a sewage treatment plant is virtually unrepresented in the literature.

To begin the study of material balances, the importance of knowledge about the conditions under which a plant is operating cannot be over-emphasized. Backmeyer (4) states that

> "Efficient sewage plant operation depends to a great extent on the plant supervisor's knowledge of the volume of flow and the quantity of solids entering and leaving his plant."

This quote points out the two things which are required to achieve adequate definition of treatment plant operation, flow metering and quantitative analysis of wastewater parameters.

First, flow metering will be discussed. Anon. (5), in a section of the periodical devoted to general information for

operators states

> "...no reasonably accurate evaluation of plant performance can be made without measuring sewage flows...."

If an operator has knowledge of the total volumes of flow handled by the individual units, it will aid him in the proper operation and maintenance of those units. Flow metering can:

1. provide information on operating efficiency,
2. make possible intelligent control of unit operations such as dosing rates for trickling filters, sludge loading in digesters, chemical feeding, etc.,
3. be used for charging rates, and
4. provide data for records.

Adequate metering of wastewater, sludges, air, gases, and recycle flow is seen to be paramount in treatment plant analysis.

Devices to do the metering may include fill and draw containers, weirs, Parshall flumes, velocity (propeller) meters, magnetic meters, Venturi tubes, differential head meters, and others. Unfortunately, not all devices are equally suited for each task and are not without their problems. Fill and draw containers are not suited to large volumes, weirs can act as a barrier to foreign bodies, deposits may restrict the area of flow in velocity meters and Venturi tubes, pulsating flow may cause a magnetic meter to over-indicate a flow, and a submerged Parshall flume requires a correction factor to be applied to its meter. Metering of the fluid streams in a treatment plant can be accomplished with reasonable accuracy. Venturi tubes can meter within 2% (6) and, velocity and differential head meters with comparable accuracy. For the more non-Newtonian fluids difficulties arise, but Monroe and Brown (7) evaluate the accuracy of sludge flow in a Venturi tube meter at 1.5% (with back flushing

of pressure gauge lines). Most sludges are metered by multiplying pump capacity times operating times for centrifugal pumps, or multiplying the number of revolutions times displacement for positive displacement piston pumps. These latter two methods cannot always be relied upon. Horn, et al., (12) attempted a total phosphate balance in an activated sludge plant and come up with a 33% error in their results. They said

> "The 33% of unaccounted for phosphate was higher than anticipated; however the error was attributed partly to 'estimating' waste sludge flow from a pump capacity and elapsed pumping times."

In general, from the research conducted in this study, it was found that most plant operators would overestimate their sludge flows or have no idea what volume of sludge is being processed.

The second item in the adequate definition of plant operation is quantitative analysis of the waste treated. Various references, (4), (5), and (8), put great emphasis on the quality of the analysis. The analysis is composed of two parts: sample collection and sample evaluation. Sample evaluation for this study was conducted in accordance with references (1) and (2). Further elaboration of sample evaluation will not be made here.

Backmeyer (4) also touches on sample collection.

> "Carelessness in taking and handling sewage samples cannot be permitted if a sound and reliable appraisal of plant performance is the ultimate aim of the sampling program."

In essence, the material which is being sampled should be adequately represented. In getting a representative sample, the sample point should be judiciously selected. Reference (5) recommends that the following samples be taken at the locations indicated:

1. raw sewage--after pretreatment,

2. settled sewage--effluent trough or weir,

3. trickling filter influent--from distribution arm,

4. trickling filter effluent--effluent trough or at secondary influent,

5. activated sludge tanks--points of greatest turbulence,

6. sludges--at pipe openings downstream of pumps, and

7. digested sludges--upon application of drying beds.

Tarazi, et al., (8) concluded in tests comparing grab and composite samples that

> "...the flow-weighted composite sampler provides the sampling technique most suitable for universally obtaining representative samples of wastewater effluent."

Composite sampling is required when the average quality of a material is wanted and when the material is to be collected over a period of time. The automatic composite sampler is best suited for these purposes. But because of the shortness of this study, the expense per automated sampler, and the diversity of sampling locations, manual, flow proportioned grab samples were taken every hour or two hours in the plants studied in this report, in an attempt to approximate the continuous, flow-weighted composite samples.

The background on flow metering and sample collection is a necessary preliminary to a material balance analysis. The importance of these two aspects was brought out in the data assimilated for several of the plants studied. A more detailed discussion of testing anomalies is given under "Discussion of Results" for the particular plant where they occurred.

Applications

The application of material balances in the field has been varied, but scarce. Examples of material balances used previously

will show the potential of the material balance as a wastewater "tool". This "tool" can be used to analyze, modify, define, and optimize a wastewater plant's operation. The following examples should point out each of the uses.

The Cranston, R.I., activated sludge plant, as described by Monroe and Brown (7), had operating difficulties due to a highly varying BOD load imposed upon them by a local brewery. They undertook a complete BOD analysis for the month of February, 1967 to define just what was happening during this period. They converted their flows and influent BOD concentration to BOD loading and plotted this on a daily basis. They found that during any one week period, the BOD loading could vary by as much as fourteen times. By using a material balance, they were able to analyze their problem and take action to correct the imbalance in BOD loading distribution.

A five year analysis on BOD and suspended solids material balances at the Covington Miss of the West Virginia Pulp and Paper Co. showed that even with increased loads, removal efficiency can be increased by

> "...continued investigation into the mechanics of the process and ANALYSIS of long term operating data have aided immeasurably in maintaining a high quality of effluent."(9) (Emphasis added.)

In this case the material balance was used to understand what was happening in the treatment process. Once the knowledge was gained, they could MODIFY the operation to OPTIMIZE removal.

A use of the material balance not mentioned heretofore is for purposes of comparison and evaluation. An unusual situation exists in Tucson, Arizona, where the treatment plant there consists of an activated sludge system in parallel with a trickling filter plant.

Both parts were designed to the same capacity, and both parts received about one half the same raw sewage. E. O. Dye (11) used suspended solids and BOD material balances to evaluate the efficiency and costs of each part of the plant. The material balance enabled a clear presentation of data. Activated sludge costs per pound of BOD removed was $.0265 as compared to $.0233 for the tricling filter. When power costs were subtracted from each system, the costs were more equal: $.0201/#BOD removed vs. #.0197/#BOD removed. The balances showed that the activated sludge process removed 317 pounds more BOD per million gallons influent and 167 pounds more suspended solids than the trickling filter process. The Tucson plant is an excellent example of how a material balance can be put to use in helping others make decisions on the relative merits of respective treatment plants.

Vacker, et al., (16) compared phosphate removal efficiencies for various types and degrees of wastewater treatment. Their aim was to correlate phosphate removal with operating parameters. By using phosphate balances to a certain extent, they were able to derive regression equations that defined phosphate removal in terms of mixed liquor suspended solids, effluent ammonia, and effluent BOD. From these equations and other information they could make operating recommendations to obtain maximum phosphate removals.

> "Balance data on the fate of nitrogen in municipal treatment plants could not be found in the literature. A series of field surveys was conducted to determine whether deliberate MODIFICATIONS might increase nitrogen removal in municipal plants...." (14) (Emphasis added.)

This quote was the opening paragraph in a report that sought to increase the efficiency of nitrogen removal in contemporary

treatment plants. This is probably the best example of material balance application. Here the material balance was used to tell how much, when, and where nitrogen sources were coming from within the plant. The authors were able to understand what they had to do to increase nitrogen removal efficiency. It cannot be overemphasized the importance a material balance can play in understanding how a treatment plant operates. A quote from Barth, et al., (14) summarizes nicely part of the objective of this study:

> "In order to determine accurately the true efficiency of the unit operations and to understand the influence of plant operation, mass relationships of the various process streams that recognize the total load placed on the process by the influent waste as well as internal feedback sources are useful."

CHAPTER III

DESCRIPTION OF EXPERIMENTAL APPARATUS AND TESTS

Objective

The research was conducted to determine the distribution of selected wastewater parameters through various types of sewage treatment plants in the Colorado area. The distribution analysis encompasses all plant operating units with emphasis on the sludge handling processes. Once the various parameter distributions are defined, they will be used as an analytical "tool" to aid in the understanding of how each plant functions.

Selection of Testing Parameters

The parameters listed in Chapter I, and given again here for easy reference, represent the major wastewater pollution parameters which have been of concern and are presently of concern to plant administrators, public health officials, and those with an interest in improving the water environment.

Biochemical Oxygen Demand (BOD)
Chemical Oxygen Demand (COD)
Total Kjeldahl Nitrogen (TKN)
Total Phosphates (as $PO_4^{\equiv}$)
Total, Volatile, and Fixed Solids
Total, Volatile, and Fixed Suspended Solids

1. BOD and Suspended Solids

These two wastewater parameters are discussed together because they have been used concurrently for effluent standards for wastewater, the design of treatment plants, and the evaluation of operating treatment plants. These parameters have to be included in any study dealing with sewage treatment plants if results are to be

compared with other studies, and if readers in the wastewater field are to understand easily the material presented. Standards in the State of Colorado require 80% of the BOD of the influent raw sewage to be removed by municipal wastewater treatment plants.

2. Chemical Oxygen Demand (COD)

This parameter was selected because of its ever-increasing use in the wastewater field. The COD test has several advantages over the BOD test:

a) It is not susceptable to biological toxins or acclimation of the seed culture.

b) It more closely represents the total oxygen demand of a waste, except that it will not oxidize straight-chain aliphatic compounds, aromatic hydrocarbons, or pyridine to any appreciable extent. It will oxidize the carbonaceous organic material, the oxidizable nitrogen, and certain chemical reducing compounds.

c) It takes less time to run a complete test.

d) Errors in testing can be corrected without a sizeable loss in time.

3. Solids--Total, Volatile, and Fixed

This parameter is not widely used as a criteria for plant operation. Probably the reason for this is that only a small portion of the total solids in wastewater is visible and treatable. The major portion is made up of dissolved, inorganic salts which pass through treatment plants relatively unchanged. The magnitude of total solids concentrations in wastewater is proportional to the number of use increments (the number of times a water has been reused by different communities). This parameter is more useful to plants that have anaerobic sludge digestion or activated sludge secondary treatment. A well-digested sludge has an "ash" content (amount of inorganic solids) of about 50%. Values less than this

may indicate further digestion is required. When the fixed solids content in an activated sludge becomes too high, the sludge has to be wasted to provide an adequate food to microorganism ratio to continue proper operation. These are examples of how the total solids parameter can be used in a treatment plant.

4. Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen represents the ammonia and organic nitrogen in a waste. It does not include the nitrate and nitrite states of oxidized nitrogen. Because of the ever-increasing concern for pollution abatement and because nitrogen is a nutrient which may promote algal blooms in rivers and lakes, and eutrophication of lakes; it was decided to determine the fate of the nitrogen entering a treatment plant even though the plant was not designed specifically for the removal of nitrogen.

5. Total Phosphates

Since phosphates are also nutrients, the reasons for the use of this test are the same as for nitrogen.

Sampling Techniques and Equipment

The proper collection of samples has been discussed before and its importance cannot be overemphasized. The difficulty of proper sampling should not be underestimated. The data upon which conclusions are made are dependent on the quality of the sampling. In this study, it had to be assumed that the sampling day was an "average day" in the operation of the plant. To insure that this "average day" was well represented by the samples taken, the samples were composited over the 24 hour period. Twenty-four hour composite sampling only assumes that the wastewater already in the plant will

be similar to the wastewater in the plant during any other 24 hour period. Composite sampling was accomplished manually in this study. The manual sampling was conducted hourly unless otherwise indicated for specific plants. This hourly sampling consisted of metering influent flow, taking samples proportioned to this flow, and collecting the samples in a two liter plastic container. This container was refrigerated as close to $4^{o}C$ as possible. Not all flows in a treatment plant varied as the influent, hence those flows which were constant were sampled at the rate of 80 ml per hour.

At this time mention should be made of the importance of location of sampling. For samples to be representative, they must be well mixed, especially for those flows which contain particulate matter that vary in size and density. A well mixed sampling point is not as important for settled sewage. When a sample was to be taken, locations such as hydraulic jumps after flumes, weir overflows, pipe outfalls, or channels with flow velocity greater than scouring velocity were sought. Channels with low velocity and plug flow were found to be very poor locations, and samples taken from such points could not be relied upon.

Testing Apparatus and Procedure

No testing on any parameter was commenced until after the 24 hour sampling period and after the samples were returned to the University of Colorado Sanitary Engineering Laboratory. Between the end of sampling and the start of each specific test, samples were continuously refrigerated. That portion of each sample to be tested for Kjeldahl Nitrogen and COD was preserved with sufficient sulfuric acid (about 1 ml/L conc. H_2SO_4) to reduce the pH to 2 to 3

and prevent any biological oxidation. The sample portion to be used for testing for all other parameters was not chemically preserved.

All tests were conducted in accordance with reference (2) except for those modifications described below.

1. Biochemical Oxygen Demand

This test was the first one set up on the refrigerated sample. Dilution water was prepared by adding 2 ml/L of Metro Denver secondary effluent as a seed, and by aerating the water with compressed air. The Denver secondary effluent was used as seed for all the plants studied, except Boulder, to get around the problem of cultivating a seed specifically for each plant. All samples were seeded. BOD bottles with only dilution water showed an average O_2 depletion of .3 to .6 mg/L for all the tests run.

2. Chemical Oxygen Demand

Two strengths of potassium dichromate were used in the tests-- .25 and .025 Normal. Sample sizes were varied so that approximately half of the dichromate was consumed in the test.

An attempt was made at the beginning of the research to utilize the rapid COD test developed by Jeris (18). Testing precision was quite good, but the accuracy comparisons with the standard test were not close enough to be relied upon. Since samples were taken only twice at each plant, no correlation between the rapid and standard test could be made. Therefore, the rapid test was not used.

3. Suspended Solids

The filtering media for this test was modified in an attempt to increase sample sizes and decrease filtering time. By increasing

sample size to be filtered, it was hoped that test results would be more reliable.

The modification consisted of placing a specially prepared asbestos mat over the glass filter disk in a number 4 Coors filtering crucible. The asbestos mat was prepared by washing a medium grade asbestos fiber repeatedly in 1500 ml beakers to remove all of the fine fibers. The washing process can be closely compared to the elutration process and was carried on until the water to be decanted was clear. The fine fibers seen suspended in the decant water were probably the material which caused the faster clogging during filtration when the asbestos cream method is used. Once the washing process was completed, the filtering crucible is placed under a vacuum with the glass fiber disk in place. Small amounts of the washed asbestos fiber were placed in the crucible and then distilled water was washed through to even out the mat. This step was repeated several times to build up the thickness of the mat. The objective is to provide filtration in depth so that most of the suspended particles are removed before they reach the glass fiber disk since the disk itself was found to have very little filtering capacity. This prefiltering prevents clogging of the glass fiber disk which reduces the filtering rate. Volumes of up to 6 to 8 times as much as what can be filtered with just the disk have been consistently filtered during this research.

After the mat was finished, the crucible was dried to a constant weight at 103°C and then fired in a muffle furnace. The prepared crucible was cooled and stored in a desiccator until use. The crucible can also be reused after certain wastes have been filtered.

Crucibles that have filtered wastes with very fine particles such as digested sludges can only be used once.

One other modification was used in this test. The samples were placed in graduated cylinders and allowed to stand for two hours before filtering. This allowed some of the suspended solids to settle. These settled suspended solids were filtered last and prevented premature clogging of the filter.

Fixed suspended matter was determined by incineration at 600°C ± 5°C for thirty minutes. An attempt was made to determine the suspended solids of all wet sludges. This was done by diluting 10 ml of a wet sludge (measured with a wide tip pipette) to one liter and homogenizing it for five minutes in a Waring blender. The filtration proceeded as described above. The dilution factor was applied to the test results to get a final result. Two tests were run on each sample point.

4. Total Solids

The fixed fraction of the total solids test was determined by ignition in a muffle furnace at 600°C ± 5°C for thirty minutes. Reference (1) now recommends ignition at 550°C. Two total solids tests were run at each sample point.

5. Total Kjeldahl Nitrogen

Analysis was performed using the titrametric method. All sludges were analyzed by diluting 10 ml of wet sludge to one liter and treating this as a liquid waste. The procedure outlined on page 469 of reference (2) for preparing sludge samples for analysis was not followed because of the number of samples to be tested for each plant. Only the diluted wet sludge volume was used as a sample.

6. Total Phosphate--Dissolved and Suspended

High concentrations of total phosphate have been found in this work. Greater than 30 mg/L was not uncommon in the wastewaters tested. This agrees with values found elsewhere, (12) and (16). In order to prevent inordinate dilutions of samples to get the concentrations in a workable range, a procedure was sought which would be accurate in these higher ranges. After much investigation by another investigator (23), a combination of steps was found which gave consistent results on wastewaters which had suspended matter. With other methods, this suspended matter was not effectively digested which interfered with light transmittance in the specto-photometer. This interference often caused wide variances in the balnks used to null out particulate interference. Adequate digestion of all phosphate in the suspended matter and the suspended matter itself was sought to remove interfering turbidity during spectrophotometer analysis. The potassium persulfate digestion method as described on page 526 of (2) was used, except that .75 gm $\pm$ .02 gm of persulfate in crystalline form was added to each sample bottle. This technique digested the sample very well.

The digested sample was analyzed for orthophosphate by the Aminonaphtholsulfonic Acid method described in reference (1). Since only total phosphate was sought, samples were not preserved chemically.

CHAPTER IV

RESULTS AND DISCUSSION

Description of Material and Format

The material included in this chapter is presented in seven sections, one for each of the sewage treatment plants studied. The material presented is as representative of normal plant operation as conditions during the sampling period would permit. Any deviation from normal plant operation during sampling is indicated under the respective plant's description. It was realized that to sample during a literally "average" day would be impossible. With this in mind, as much information as possible is provided to adequately describe the conditions under which the sampling was conducted. This material is presented in Appendix I for trickling filter plants, and in Appendix II for extended aeration and activated sludge plants.

Removal efficiencies for the units and the plant are shown in the first table of each section. This data is then plotted to show the residual after each unit in the plant. In each section are a number of material balances representing the actual results of laboratory tests and field data. Results were not adjusted to make the parameters balance. To show the amount of error in balancing across any unit, a table is included in each balance sheet showing percent error across primary and secondary clarifiers. The pounds recorded for each parameter at the different points indicated, represent the number of pounds of that parameter that passed that particular point in twenty-four hours. These masses have been normalized to a plant influent flow of one million gallons per day.

A discussion of any interesting or unusual cost information is given for each plant, with the summary and comparisons of all plants, is presented in Appendix III. Appendix III shows the costs, broken down into operating, capital, and total per MGD treated, and total per pound pollutant removed, for each plant and sampling period.

The last part of each section in this chapter discusses results of testing, plant operating conditions, and other interesting points that can be concluded from the data collected. The experimental data used to develop efficiency curves and material balances is found in Appendices IV through X.

Discussion of Flows

Prior to discussing the actual data and results, a few words about volumes of flow are appropriate here as they have been found to have a significant affect on the results presented. It was found, in the course of this study, that the biggest obstacle to obtaining accurate material balances was the determination of volumes of sewage flow. The question was raised as to the accuracy of various flow meters in a plant. Data on percent efficiency of different types of meters is scarce. Also, there was insufficient time and knowledge to evaluate the efficiency of the flow meters in all the plants studied. Hence, assumptions had to be made. One was that the main flow meter in a plant, usually an influent Parshall flume, gave the correct reading. The other was that recycle meters, sludge flow meters, and operating personnel estimates gave values that should be checked by material balance computations.

Material balance computations were used across clarification units to determine primary sludge, secondary sludge, or recycle

flows. The influent flow volume and pollutant parameter concentrations determined by laboratory analysis were assumed to be correct. The volume of sludge flow was the unknown. A hypothetical balance is shown to illustrate the procedure.

Unit Influent Flow = 1 MGD
Influent Parameter = 250 mg/L

Operational Unit

X = Unknown Sludge Flow
Sludge Parameter = 1600 mg/L

Unit Effluent Flow = (1-X) MGD
Effluent Parameter = 100 mg/L

$$\text{Pounds IN} = \text{Pounds OUT}$$

$$1\ \text{MGD} \times 250\ \text{mg/L} \times 8.34\#/\text{Gal.} = (1\text{-}X)\ \text{MGD} \times 100\ \text{mg/L} \times 8.34\#/\text{Gal.} + X\ \text{MGD} \times 1600\ \text{mg/L} \times 8.34\#/\text{Gal.}$$

$$X\ \text{MGD} = \frac{1\ \text{MGD} \times 250\ \text{mg/L} - 1\ \text{MGD} \times 100\ \text{mg/L}}{1600\ \text{mg/L} - 100\ \text{mg/L}} = \frac{150\ \text{mg/L} \times \text{MGD}}{1500\ \text{mg/L}} = .1\ \text{MGD}$$

This procedure was repeated for each of the six parameters tested, and an arithmetic average of the sludge flow was compared with the plant flow or plant estimate. A judgement was made as to the most likely flow, and that flow was used in further computations. Specific cases will be pointed out below where the flow volume was believed to be the reason for inaccuracies in the respective material balance. In general, it was found that plant operators and administrators could not accurately state what the flows were on lines that were not metered. "I believe" and "about" were frequently used terms.

If flow volumes can be determined with some degree of certainty, the material balance could receive wider acceptance as a useful tool to understand and control treatment plant operation.

BOULDER SEWAGE TREATMENT PLANT

BOULDER, COLORADO

Description of Plant

The 75th Street Boulder treatment plant is a 5.2 MGD design capacity standard-rate trickling filter plant presently operating at greater than seven MGD. The plant receives primarily domestic sewage from the City of Boulder. After the influent sewage passes through conventional grit removal, it enters two primary settling basins which are operated in parallel. The primary basin effluent along with part of the trickling filter effluent is pumped at a constant rate of 11.5 MGD onto two standard-rate trickling filters which are in parallel. The filters are 155 feet in diameter, 9 feet deep, and have a 3 inch to 4 inch cut rock media. Trickling filter effluent is clarified in two parallel clarifiers prior to being chlorinated and released to Boulder Creek. Secondary sludge is recycled to the head of the plant where th sludge is removed by the primary basins. Only primary sludge is pumped to a holding tank where it is aerated and subsequently vacuum filtered. Two coil-spring vacuum filters are operated about eight hours a day with the filter cake being hauled to landfill by ten-ton trucks. Filtrate is returned to the head of the plant. The Boulder plant was first put into operation in 1959 as a 5.2 MGD treatment plant, and is presently undergoing expansion to 15.6 MGD capacity.

There are two recycle flows in the plant. The secondary sludge, a relatively mild waste, is recycled to the head of the plant. The other recycle is the trickling filter effluent back onto the filter.

The difference between pump capacity of 11.5 MGD and primary effluent flow is recycled.

Refer to Appendix I for additional information on plant operation conditions during the sampling periods. A schematic flow diagram giving flows during the two sampling periods follows in Figure 1.

Description of Sampling

The Boulder plant was the first plant studied. Because it was the first, several errors in judgement and sampling technique occurred. The Boulder plant is sampled by its own operators on a two hour, composite basis proportioned to the influent flow. It was found that their sampling technique did not give a high level of confidence. As a consequence, all subsequent sampling was conducted by the author, except for the Metropolitan Denver plant which presented a physical impossibility for one man to sample.

The trickling filter influent was not sampled. The vacuum filter filtrate was sampled during filter operation for about eight hours per day, and the secondary sludge recycle was sampled hourly from 8:00 AM to 5:00 PM. This was probably inadequate technique for the secondary sludge because the recycle waste concentration increased greatly for the 2 to 3 minutes when the raking mechanism in the clarifier passed over the sludge sump. Continuous sampling is really needed for streams such as this. The sampling period was from 12 midnight to 12 midnight on both the 16th and 24th of June, 1971. No changes in plant operating procedures occurred during either testing period. Plant/unit removal efficiencies based on waste concentrations follows the schematic flow diagram.

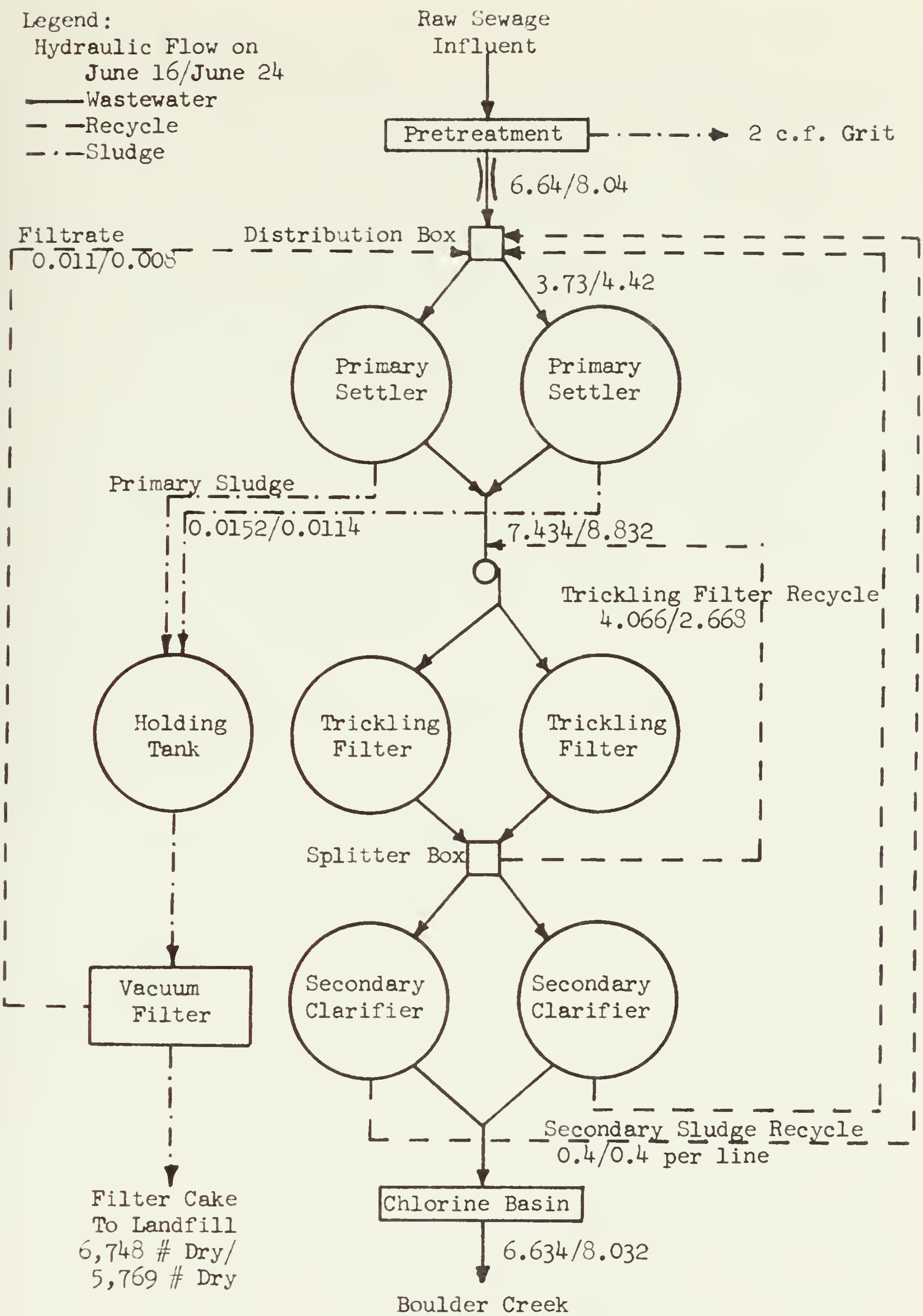


Figure 1. Hydraulic Flow Diagram for Boulder

All flow values are in MGD.

TABLE I

Plant/Unit Removal Efficiencies for Boulder Sewage Treatment Plant															
Para-meter --- Test-ing Period	Plant	Primary Settlers				Trickling Filters				Secondary Clarifiers				Overall Plant	
	Inf. mg/L	Pri. Inf. mg/L	Pri. Eff. mg/L	% of Pri. Inf. Removed	% of Plant Inf. Removed	Tri. Fil. Inf. mg/L	Tri. Fil. Inf. mg/L	% of T. F. Inf. Removed	% of Plant Inf. Removed	Sec. Inf. mg/L	Sec. Eff. mg/L	% of Sec. Inf. Removed	% of Plant Inf. Removed	Plant Eff. mg/L	% Over-all Removed
BOD-I	179	225	135	40	25	115	82	28.7	54.2	82	39	52.5	78	15	92
BOD-II	169	150	139	7	18	132	111	16	34.3	111	59	47	65	--	--
COD-I	344	420	206	51	40	177	126	29	63.4	126	93.5	26	73	134	61
COD-II	264	305	290	5	-10	251	124	50.6	53	124	114	8	57	130	51
TKN-I	17	16.7	17.3	-4	-2	16.3	15.6	4.3	8	15.6	12	23	29.4	10.3	39.5
TKN-II	23.1	17	15.2	11	34	14.4	11.5	20	50	11.5	14	-22	39.6	13.8	40
$PO_4^{\equiv}$-I	16.6	---	14.9	--	10	14.4	13.8	4	17	13.8	13.0	6	22	13.4	19.3
$PO_4^{\equiv}$-II	15	14.7	14.2	3.4	5	14.2	14.5	-2	3	14.5	13.4	7.6	11	13.1	13
TS-I	634	657	511	22	19	508	517	-2	18.5	517	492	5	22.4	467	26.4
TS-II	729	770	699	9.3	4	683	631	7.7	13.6	631	585	7	20	620	15
VTS-I	307	315	232	26	24	237	252	-6.3	18	252	210	17	32	134	56.4
VTS-II	287	260	238	8.5	17	224	177	21	38.3	177	134	24.3	53.3	166.5	42
FTS-I	328	339	276	18.6	16	276	265	4	19	265	282	-6.4	14	333	-1.5
FTS-II	443	510	462	9.5	-4	460	455	1	-2.7	455	451	1	-1.8	453	-2
SS-I	124	132	60	55	52	56	49	12.5	60.5	49	20	59	84	---	--
SS-II	121	123	67	45	45	62	45	27.5	63	45	28.5	37	76.5	28	77
VSS-I	98	110	56	59	43	50	40	20	60	40	17	57.5	83	--	--
VSS-II	108	109	62	43	43	56	37	34	66	37	25	32.5	77	26	76
FSS-I	27	28	5	82	82	7	9	-28	67	9	3	67	89	--	--
FSS-II	13	17	5	71	62	5.7	8.5	-49	35	9	4	53	69	2	85

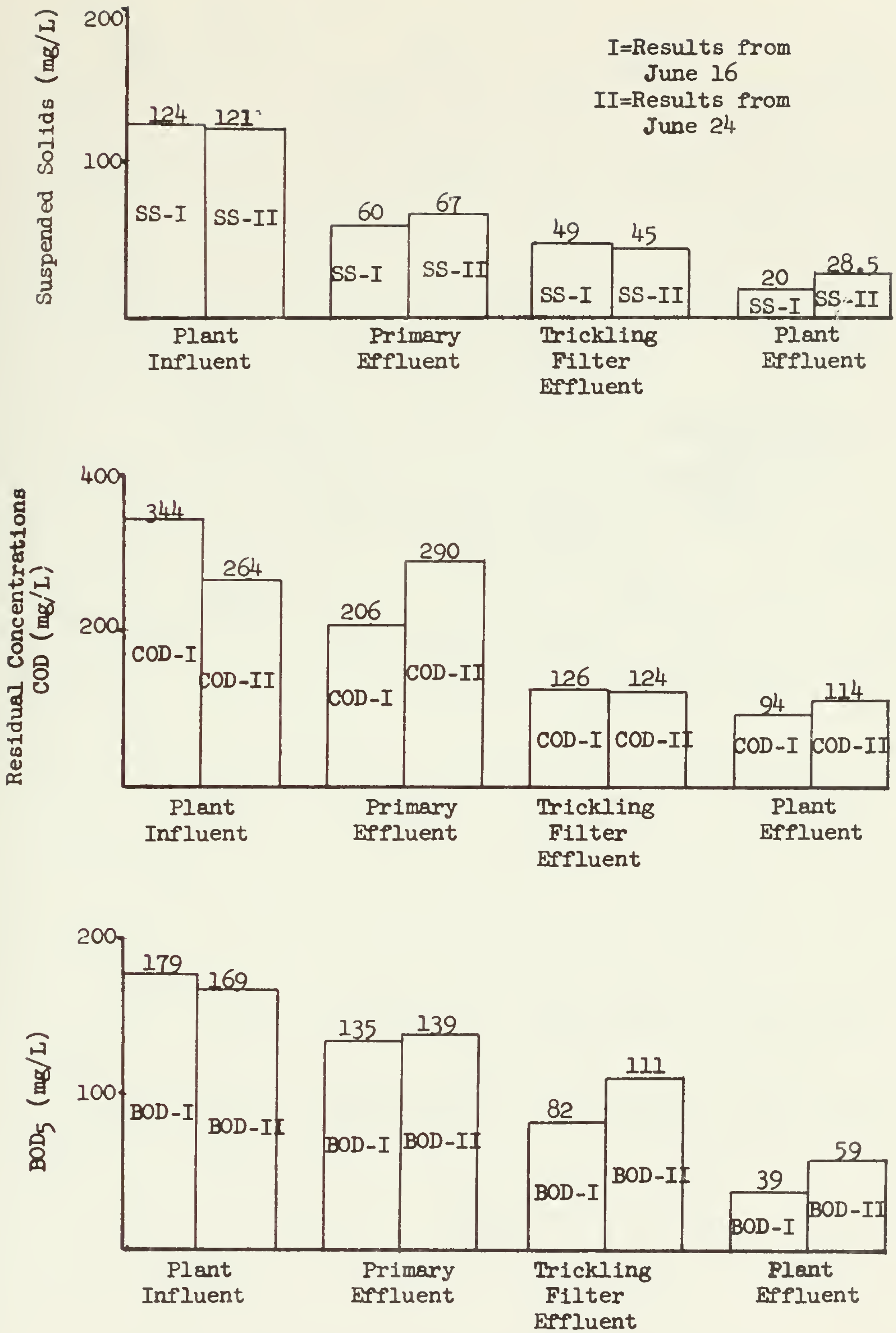


Figure 2. Residual Concentrations for Boulder

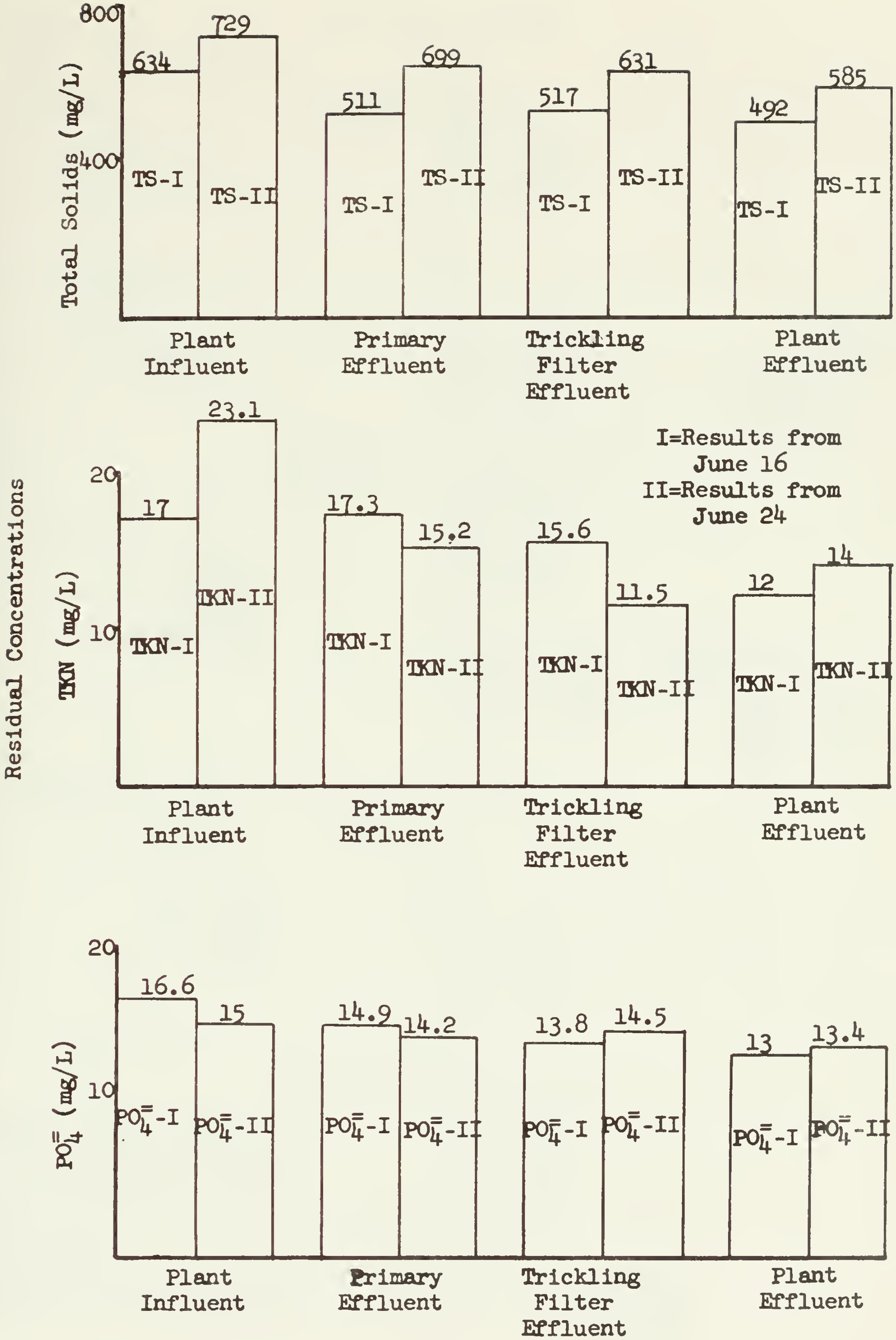
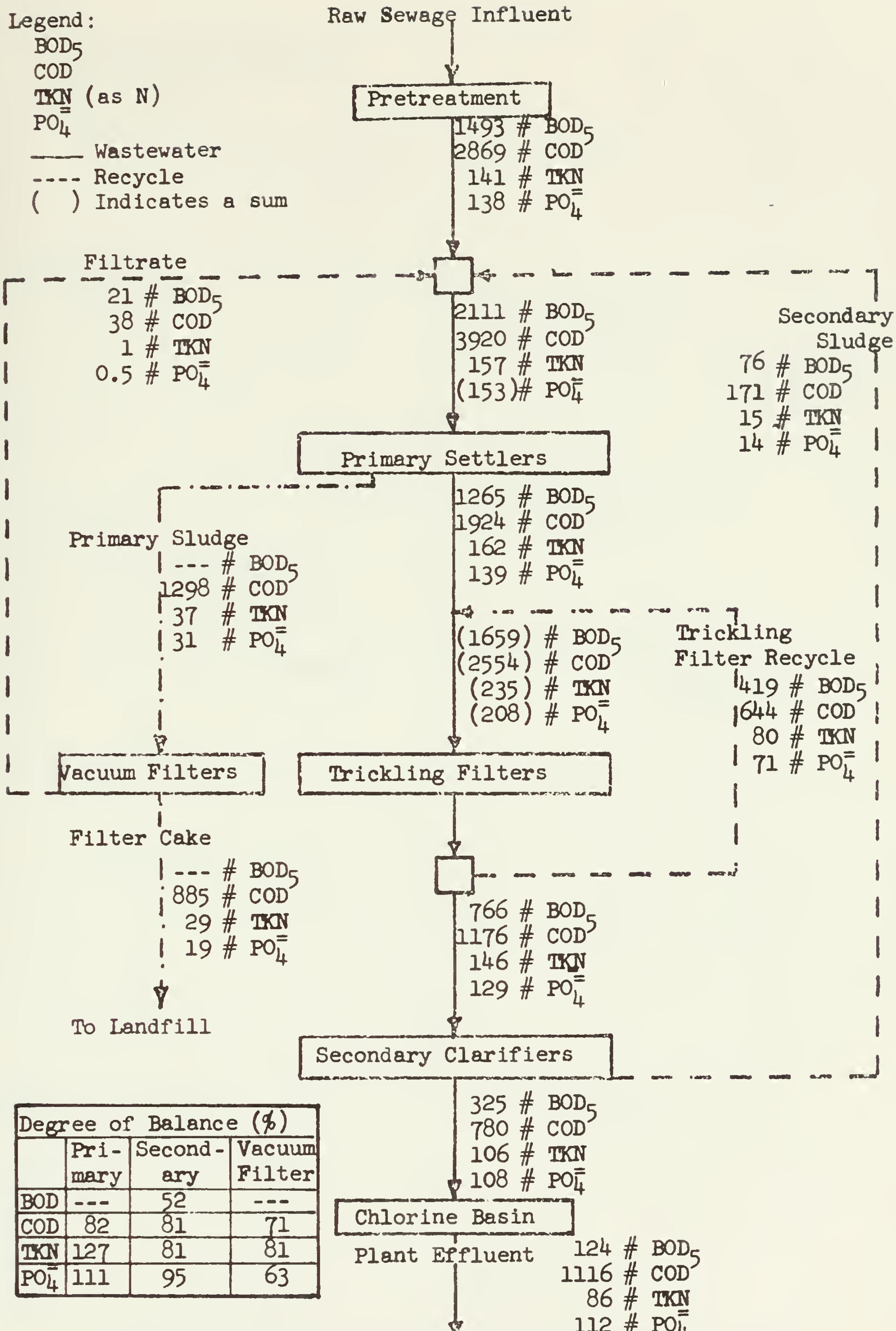
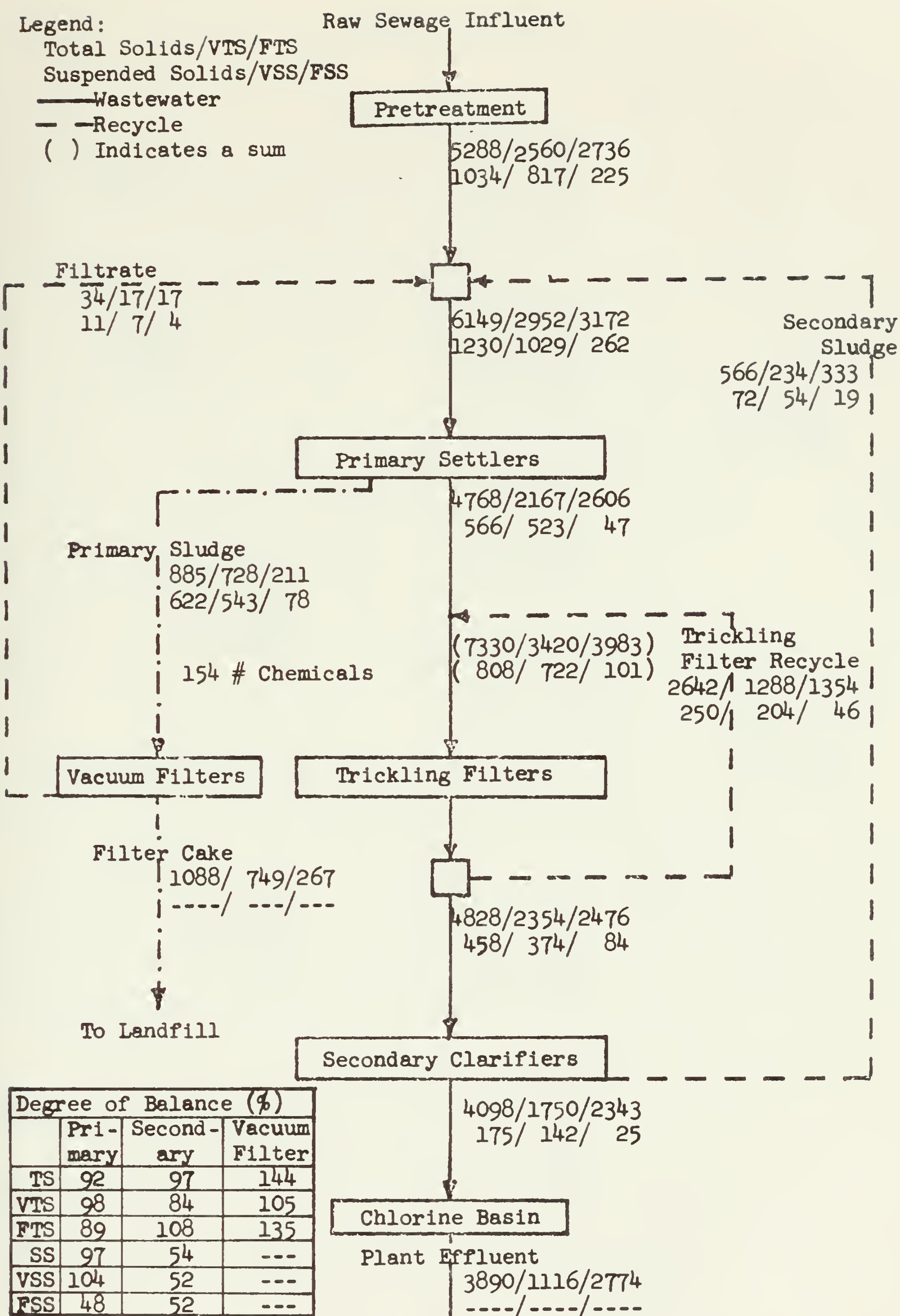


Figure 2 . (cont.) Residual Concentrations of Boulder



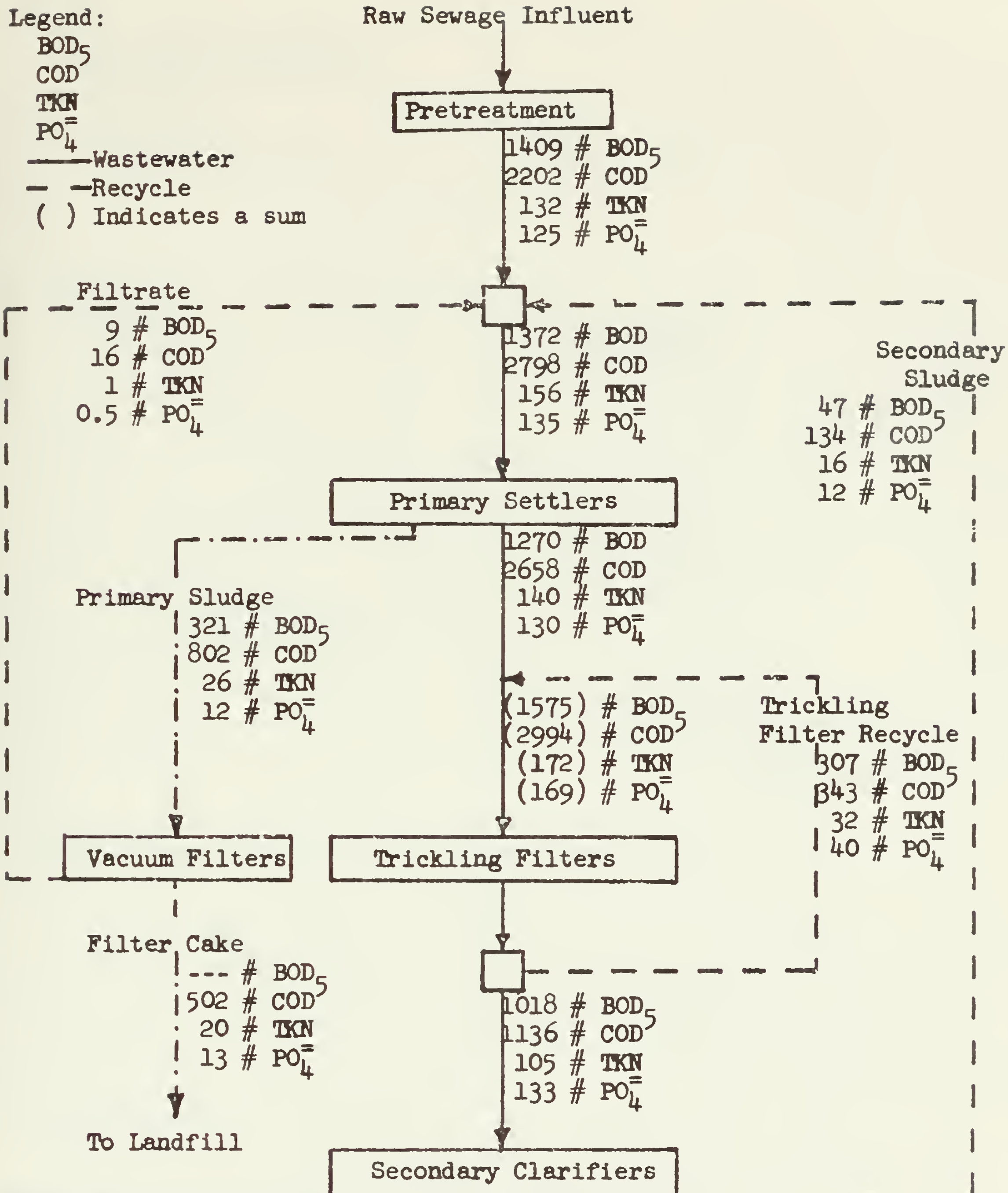
Degree of Balance (%)			
	Primary	Secondary	Vacuum Filter
BOD	---	52	---
COD	82	81	71
TKN	127	81	81
$PO_4^{=}$	111	95	63

Figure 3. Material Balances for Boulder on June 16, 1971
All values expressed in pounds per one MG influent flow.



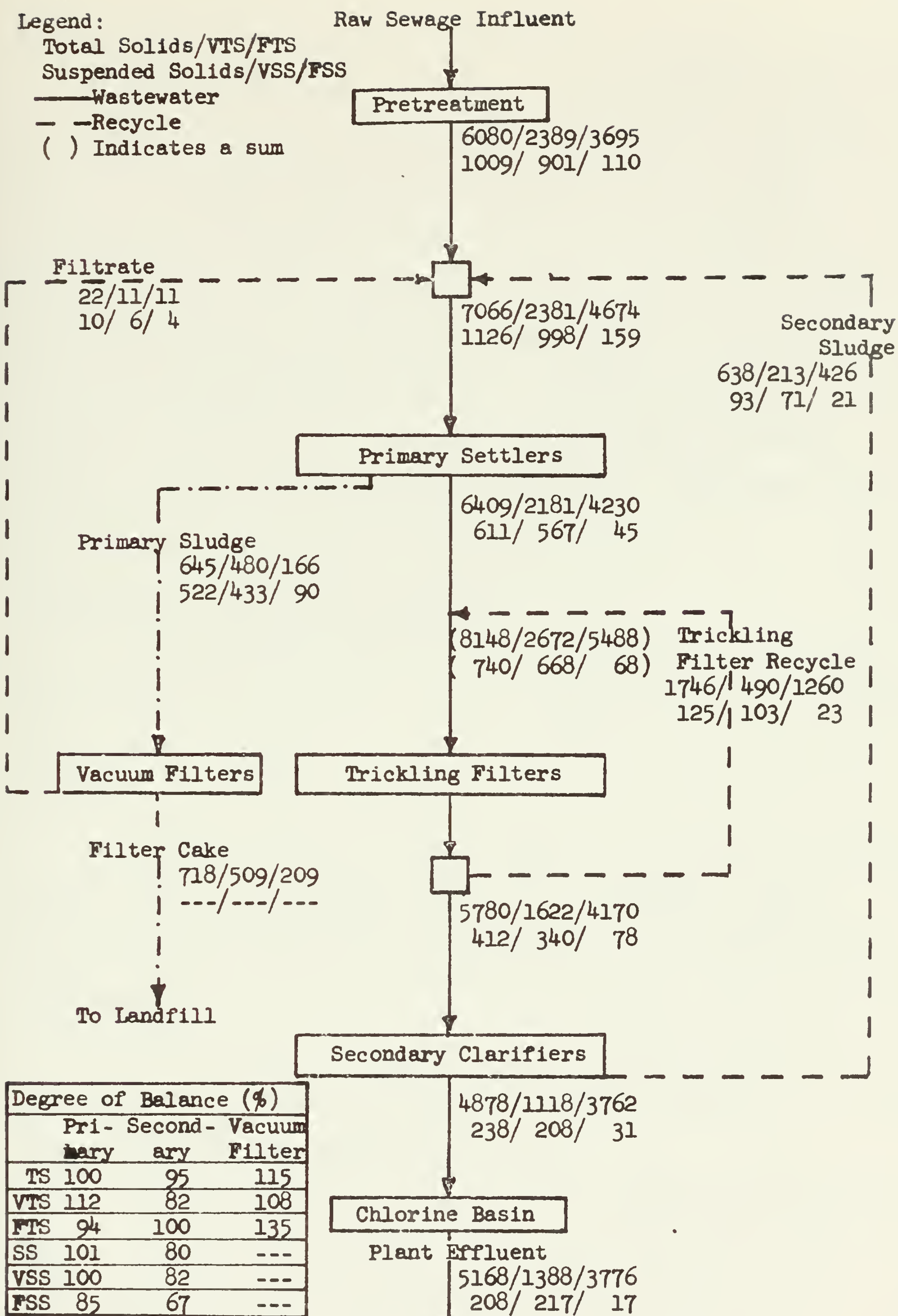
Degree of Balance (%)			
	Primary	Secondary	Vacuum Filter
TS	92	97	144
VTS	98	84	105
FTS	89	108	135
SS	97	54	---
VSS	104	52	---
FSS	48	52	---

Figure 4. Solids Balance for Boulder on June 16, 1971
All values expressed in pounds per one MG influent flow.



Degree of Balance (%)			
	Primary	Secondary	Vacuum Filter
BOD	116	53	---
COD	124	95	65
TKN	106	126	81
$PO_4^=$	105	92	113

Figure 5. Material Balances for Boulder on June 24, 1971
All values expressed in pounds per one MG influent flow.



Degree of Balance (%)			
	Primary	Secondary	Vacuum Filter
TS	100	95	115
VTS	112	82	108
FTS	94	100	135
SS	101	80	---
VSS	100	82	---
FSS	85	67	---

Figure 6. Solids Balance for Boulder on June 24, 1971
All values expressed in pounds per one MG influent flow.

Cost Analysis

All cost analysis data for Boulder, and all subsequent plants in this report, is given in various parts of Appendix III. Operational costs at the Boulder plant ran 6.5 cents/1000 gallons. Capital cost/MG was not available as these costs were paid primarily by plant investment fees. Operational costs per pound of the various pollutants removed by the Boulder treatment plant was comparable to costs at the larger Metro Denver plant. $/# BOD_5 removed was .055 at Boulder and .053 at Denver. Suspended solids costs was $.078/# removed at Boulder and $.052/# removed at Denver. Operational costs applied to each treatment unit was not available.

Discussion of Results--Testing Comments

1. The majority of balances where the raw sewage influent load was used came up low implying that the strength of the raw sewage was weak. This was probably due to sampling technique as the sample was taken in the grit chamber channel.

2. Inconsistency or irrational figures for the primary influent samples indicate that samples were taken before complete mixing occurred. This occurred mainly in Primary #2. See Appendix IV for pertinent data.

3. The secondary sludge was a relatively weak waste the majority of the time and tended to dilute the raw sewage.

Discussion of Results--Operational Comments

1. The primary sludge volume pumped was probably less than that believed pumped by the operators (56,000 gal. and 48,650 gal. for the 16th and 24th of June respectively), and greater than that

calculated on the hydraulic flow diagram (15,200 gal. and 11,400 gal. respectively).

2. Secondary sludge recycled at .8 MGD was less than the 1.0 MGD believed recycled by the operators.

3. Primary settler #1 received heavier loadings due to returned filtrate than primary settler #2 which received most of the recycled secondary sludge.

Discussion of Results--Concluding Comments

1. Figure 2. indicates that in the Boulder plant BOD_5, COD, and suspended solids appear to be removed equally well by primary settlers, trickling filters, and secondary clarifiers. See Figure

2. Total solids and total phosphate showed equal removal from each unit indicating that the $PO_4^{=}$ might have been removed in the solid form.

3. Looking at the secondary treatment (trickling filter plus secondary clarifiers) balances, 940#/MG of BOD_5 and 1144#/MG of COD were removed on the 16th of June. Percentages of primary effluent removed were 74.3% and 59.5% respectively. These same parameters were removed at the rate of 61.2% (778#/MG) and 64.5% (1712#/MG) on the 24th of June. Oxidation of BOD_5 by chlorine occurred at the rate of 2.4#BOD_5/#Cl_2 on the 16th of June. During the two sampling periods 69% (391#/MG) and 61% (373#/MG) of primary effluent suspended solids were removed.

4. The only significant removal of any nutrient was on the 24th when 20% of the TKN was removed. Otherwise no nutrients were removed by the trickling filter, within experimental error.

5. Balances on the primary settling tanks varied from 82% to 127% of the material accounted for. The secondary clarifiers varied from 52% to 128% of the material accounted for.

6. Although the filtrate recycled to the head of the plant was very concentrated, the volume of the waste was such as not to put an undue amount of waste mass back into the plant. Approximately 3/4 of the primary sludge pumped was returned as filtrate.

7. It would appear that inattention to detail in the design of recycled waste streams (filtrate and secondary sludge) causes the primary settling tanks to be loaded unevenly although they appear physically to be designed for equal loadings.

8. A flow stream that should be analyzed closer is the recycled secondary sludges. About 90% of the time the water appears relatively clean; and then as the raking mechanism passes over the collector sump, the water becomes quite foul. Hence for 90% of the time, the influent raw sewage is being diluted by this stream. If the recycle pumps could operate just for the period when the waste was concentrated, it is estimated that the hydraulic load on the plant could be reduced by 50% of the secondary sludge return stream volume or about 400,000 gallons per day. This is an example of how a material balance can be used to analyze a waste, determine the load it places on a plant, and then modify the plant to increase its efficiency.

BROOMFIELD SEWAGE TREATMENT PLANT

BROOMFIELD, COLORADO

Description of Plant

The Broomfield Sewage Treatment Plant is a high rate trickling filter plant with primary and secondary clarification. Design flow is 1.7 MGD and is presently operating at about 1 MGD. Grit is removed by an aerated grit chamber. The chamber is cleaned daily with the grit being spread over the plant grounds. Primary sedimentation is accomplished by two tanks operated in parallel. Primary effluent is passed through two rock media trickling filters operated in series. The rock media is specified as 2.5 inch to 4 inch cut rock. Two parallel final clarifiers remove the trickling filter humus and sludge which is then recycled to the head of the plant. A schematic flow diagram with flow volumes during the two testing periods is given below in Figure 7.

All sludge is removed from the primary settling tanks. Sludge from each primary is pumped to separate anaerobic digesters. Digested sludge is poured onto one of five drying beds about once a month per digester. Dried digested sludge is spread over the plant grounds. A schematic flow diagram of the sludge digestion process is included as Figure 8.

An interesting feature of this plant is the maintenance of a uniform hydraulic loading on all units within the plant. Recycle pumps are set to go off or on as determined by the influent flow. Refer to Figure for edification.

1. Recycle Pump #1, located after the first trickling filter, will come on when the influent flow drops below .9 MGD to maintain a

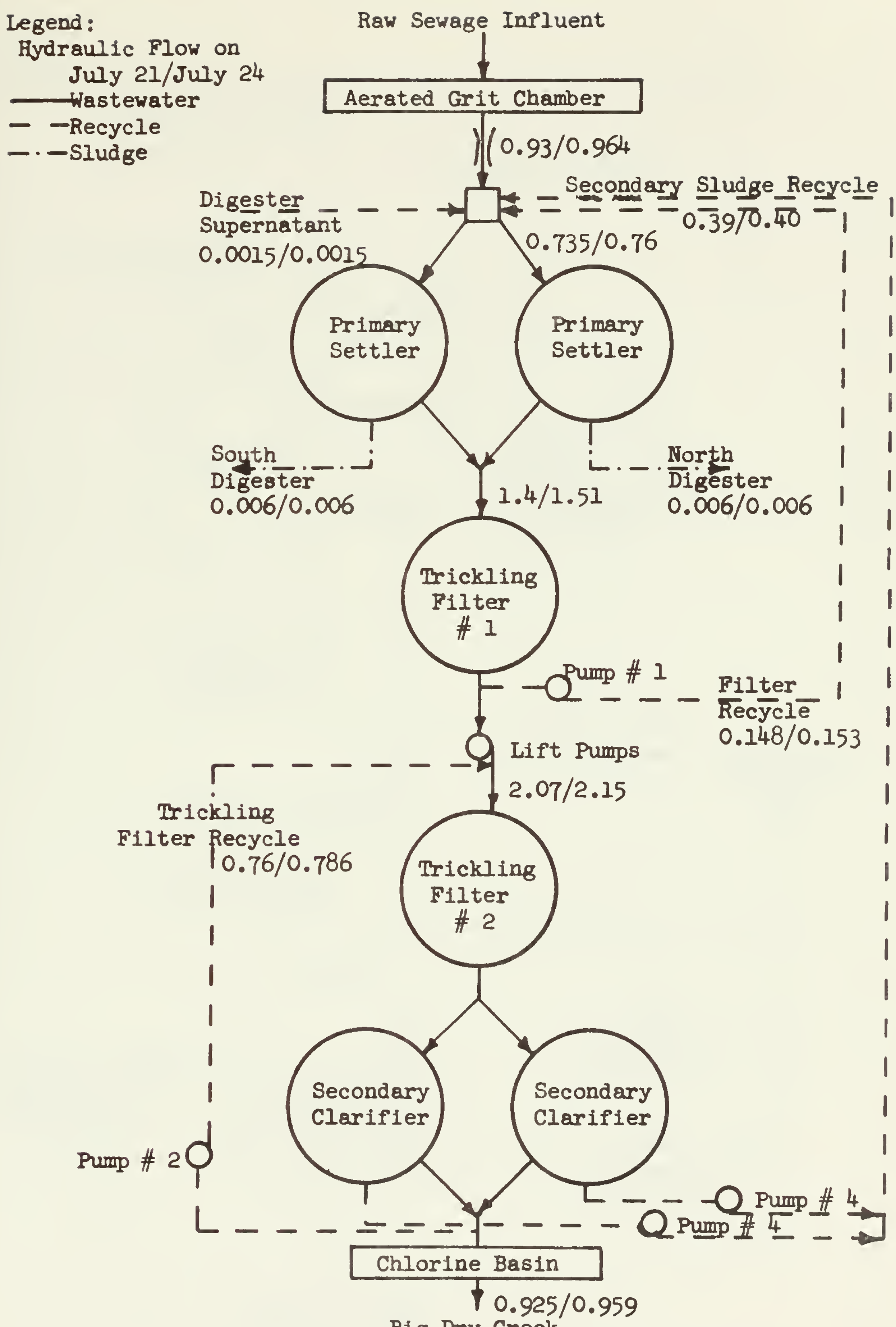


Figure 7. Hydraulic Flow Diagram for Broomfield
All flow values are in MGD.

Both digester are structurally similar and have fixed covers.

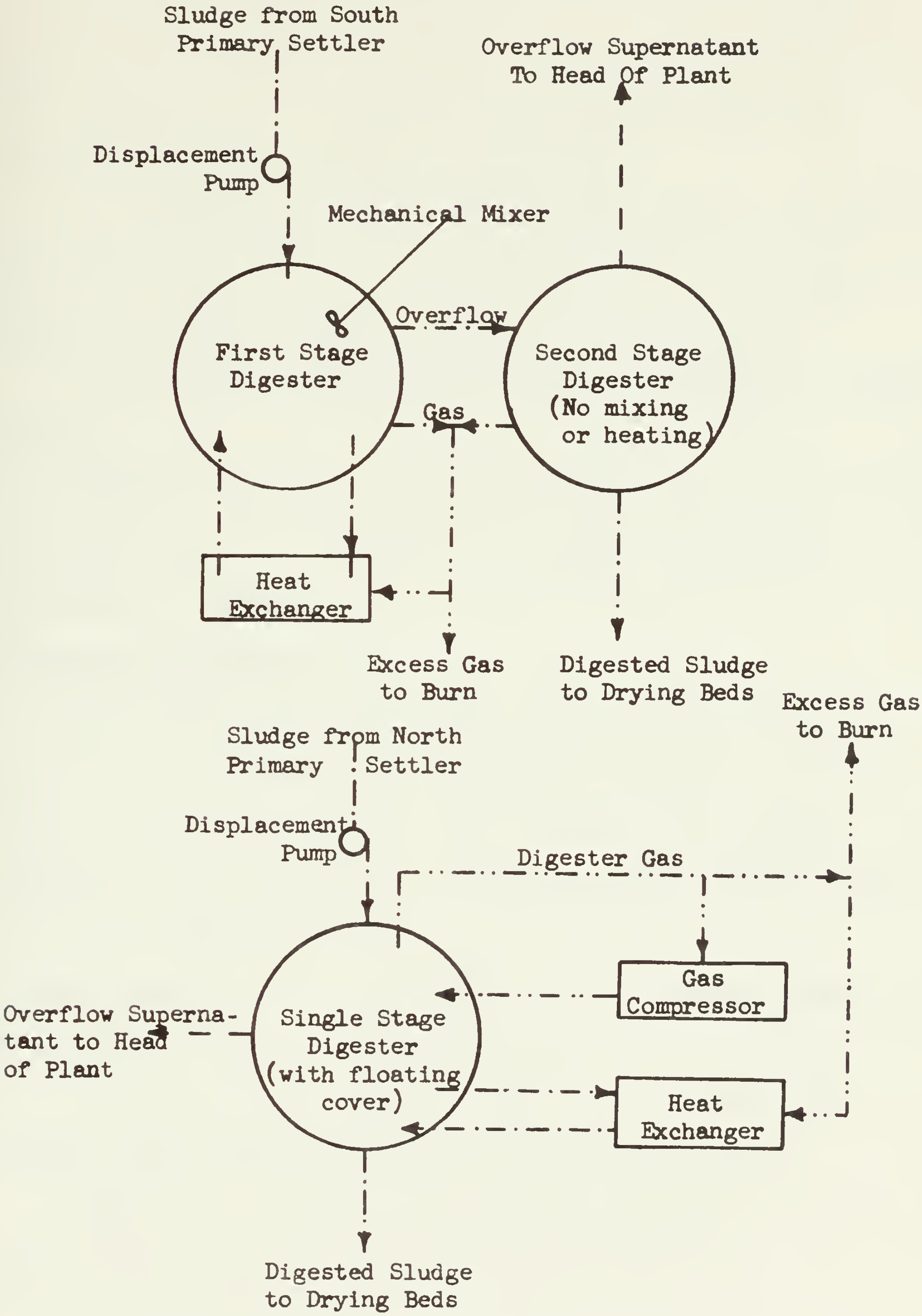


Figure 8. Schematic Sludge Flow Diagram for Broomfield

constant organic loading on Trickling Filter #1 during low flows at night.

2. Recycle Pump #2, located after the combined secondary effluents, shuts off if the influent flow is greater than 1.8 MGD. This reduces hydraulic loading on Trickling Filter #2 and the secondary clarifiers during peak flow periods.

3. Recycle Pumps #3 and #4 for secondary sludge recycle shut off if the influent flow is greater than 1.5 MGD. This reduces hydraulic loading on the whole plant during higher flows.

Pumps #2, #3, and #4 operated continuously during both sampling periods.

Appendix I gives a summary of plant operating variables during the sampling periods. Appendix V is a Summary of Data gathered at the Broomfield plant.

Description of Sampling

Proportioned grab samples taken on an hourly basis were composited over a 24 hour period. Sampling during the early morning hours occurred every two hours. The only sample not considered representative was the pre-grit raw sewage sample which was taken at a spot with inadequate mixing.

Sampling Period	Date	Weather Conditions
I	July 21, 1971	Hot, sunny
II	July 29, 1971	Cool, cloudy

Sampling period started at 3:00 PM each day for 24 hours.

There were no changes in plant operating procedures during either sampling period.

TABLE II

Plant/Unit Removal Efficiencies for Broomfield Sewage Treatment Plant

Para meter --- Testing Period	Plant Inf. mg/L	Primary Settlers				Trickling Filters				
		Pri. Inf. mg/L	Pri. Eff. mg/L	% of Pri. Inf. Removed	% of Plant Inf. Removed	T.F. # 1 Inf. mg/L	T.F. # 1 Eff. mg/L	% of Tr.Fil. # 1 Removed	% of Plant Inf. Removed	T.F. # 2 Inf. mg/L
BOD-I	162	159	79	50	51	49	45	8	72	41
BOD-II	172	42	86	39.5	50	80	45	44	74	41.7
COD-I	317	292	145	50	54.3	127	98	23	69.1	82.4
COD-II	239	225	137.5	39	42.5	143	89	38	63	75.5
TKN-I	24.1	24.3	17.	28	27	18	15	16	38	13
TKN-II	23.5		15.7	33	33	21	17	20	28.5	16
$PO_4^{=}$-I	30.4	36	22.6	37	26	28	27	4	11	25.7
$PO_4^{=}$-II	23.3	29	25.4	12	-9	23	28	-23	-20	24.8
TS-I	1062	1030	879	15	17.3	893	874	2	17.7	866
TS-II	1060	1004	960	4.4	9.5	989	986	.5	7	980
VTS-I	368	336	174	48	53	208	190	8.7	48.4	190
VTS-II	358	250	264	-6	26	273	297	-9	17	290
FTS-I	694	692	706	-2	-2	685	684	0	1.5	676
FTS-II	702	699	696	.5	1	716	688	4	2	689
SS-I	165	220	57	74	65.5	56	55.5	.5	66.4	39.8
SS-II	177.5	156	60.5	61	66	62	45	28	74.7	35
VSS-I	134	153	43	72	68	43	39	9.3	71	28.9
VSS-II	145	113	46	59	68	47	36	24	75	26
FSS-I	31	67	14	79	55	13	16	-25	48	11
FSS-II	33	44	15	66	55	15	9	40	73	9.3

Table II (cont.)

Plant/Unit Removal Efficiencies for Broomfield Sewage Treatment Plant

Para-meter --- Testing Period	Trickling Filters			Secondary Clarifiers				Overall Plant	
	T.F. # 2 Eff. mg/L	% of Tr.Fil. # 2 Removed	% of Plant Inf. Removed	Sec. Inf. mg/L	Sec. Eff. mg/L	% of Sec. Inf. Removed	% of Plant Inf. Removed	Plant Eff. mg/L	% of Over-all Removed
BOD-I	62	-51	62	62	30.5	51	81	34	80
BOD-II	50	-20	71	50	35	30	79.7	36	79.1
COD-I	76	8	76	76	56	26	82	55.5	82.5
COD-II	56	26	77	55.6	49	12	79.5	52	78.3
TKN-I	11	15	54	11.2	9.6	14	60	9.8	59.4
TKN-II	13	12	43	13.5	13	4	45	13.1	44.3
$PO_4^{=}$-I	20	21	33	20.4	21.8	-7	28	23.2	24
$PO_4^{=}$-II	22	11	5.6	22	22	0	5.6	19.3	17
TS-I	885	-2	11.5	885	852	4	19.8	851	19.9
TS-II	918	6.4	13.4	918	965	-5	9	970	8.5
VTS-I	192	-1	48	192	181	6	51	190	48
VTS-II	261	10	27	261	313	-20	17	278	22
FTS-I	693	-2.5	0	693	671	3	3.3	662	4.6
FTS-II	657	5	6.4	657	654	.5	7	691	1.6
SS-I	42	-4.2	75	41.5	12	71	93	12.9	92
SS-II	23	35.5	87	22.6	15.6	31	91	17.8	90
VSS-I	29	-1	78	29.3	9.8	67	92.3	11.7	91
VSS-II	18	32	88	17.6	6.8	61	95	8.3	94
FSS-I	12	-15	60	12.3	2.2	82	93	1.2	96
FSS-II	5	46	85	5	8.8	-76	73	9.5	71

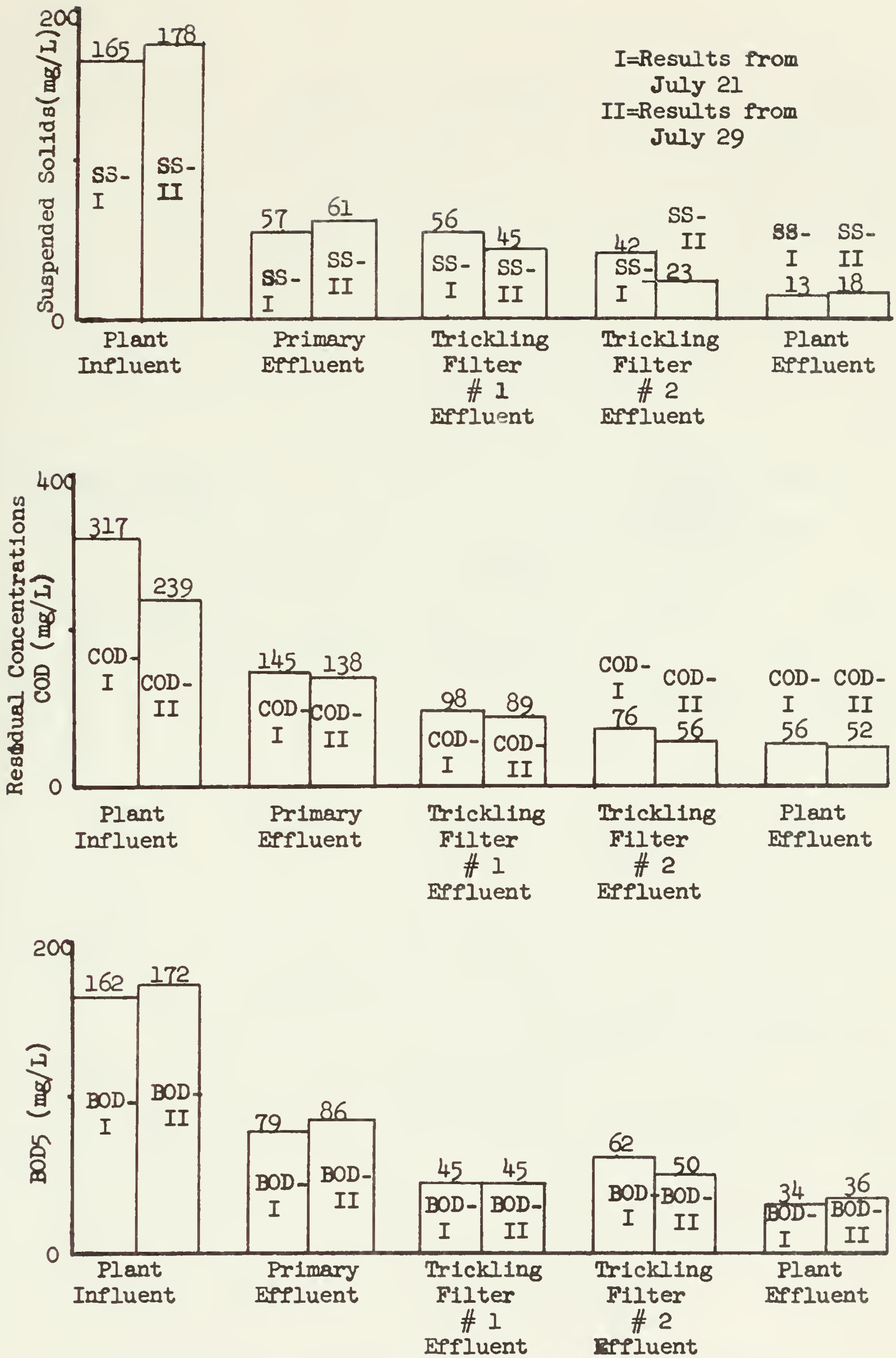


Figure 9. Residual Concentrations for Broomfield

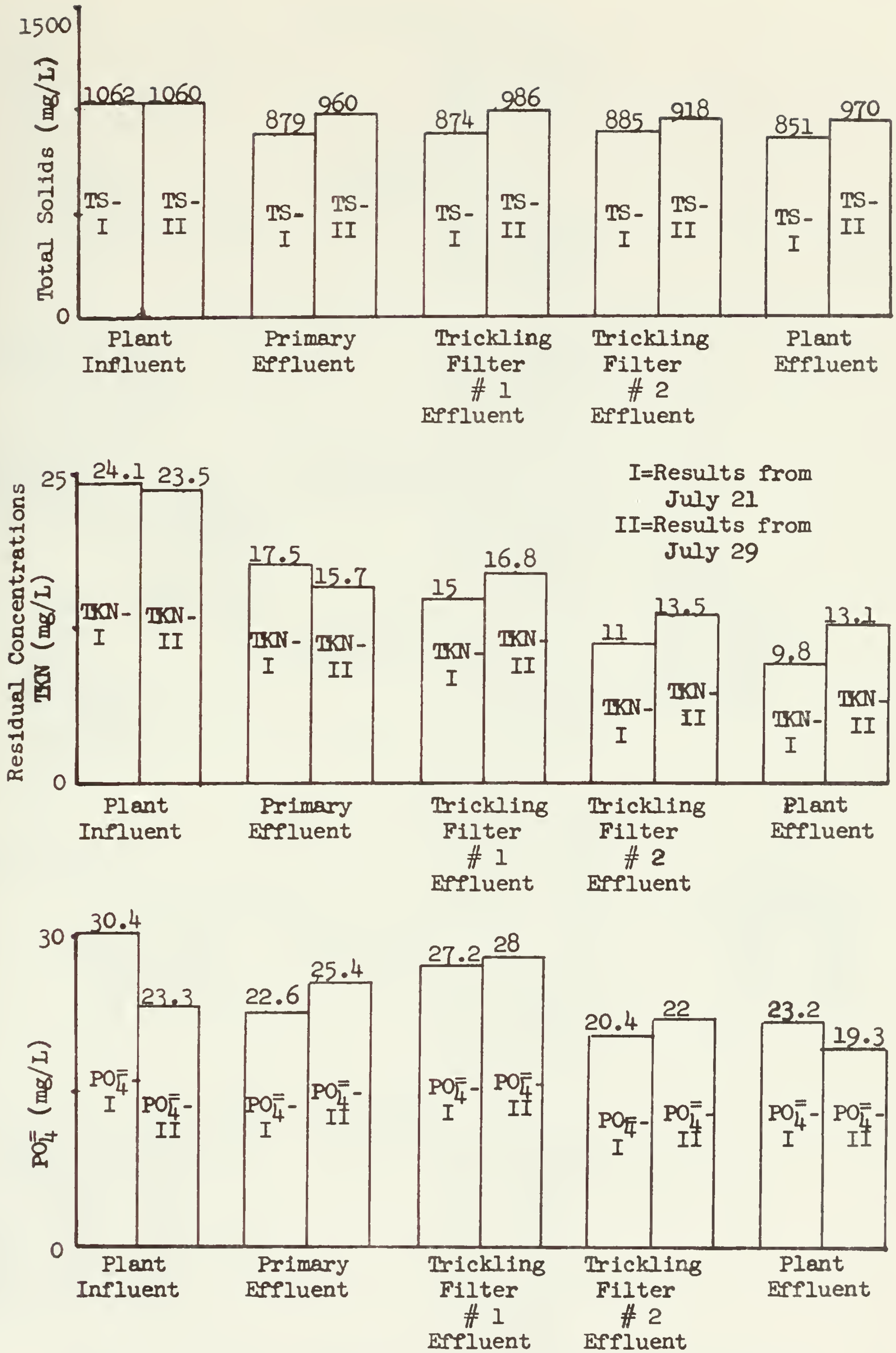
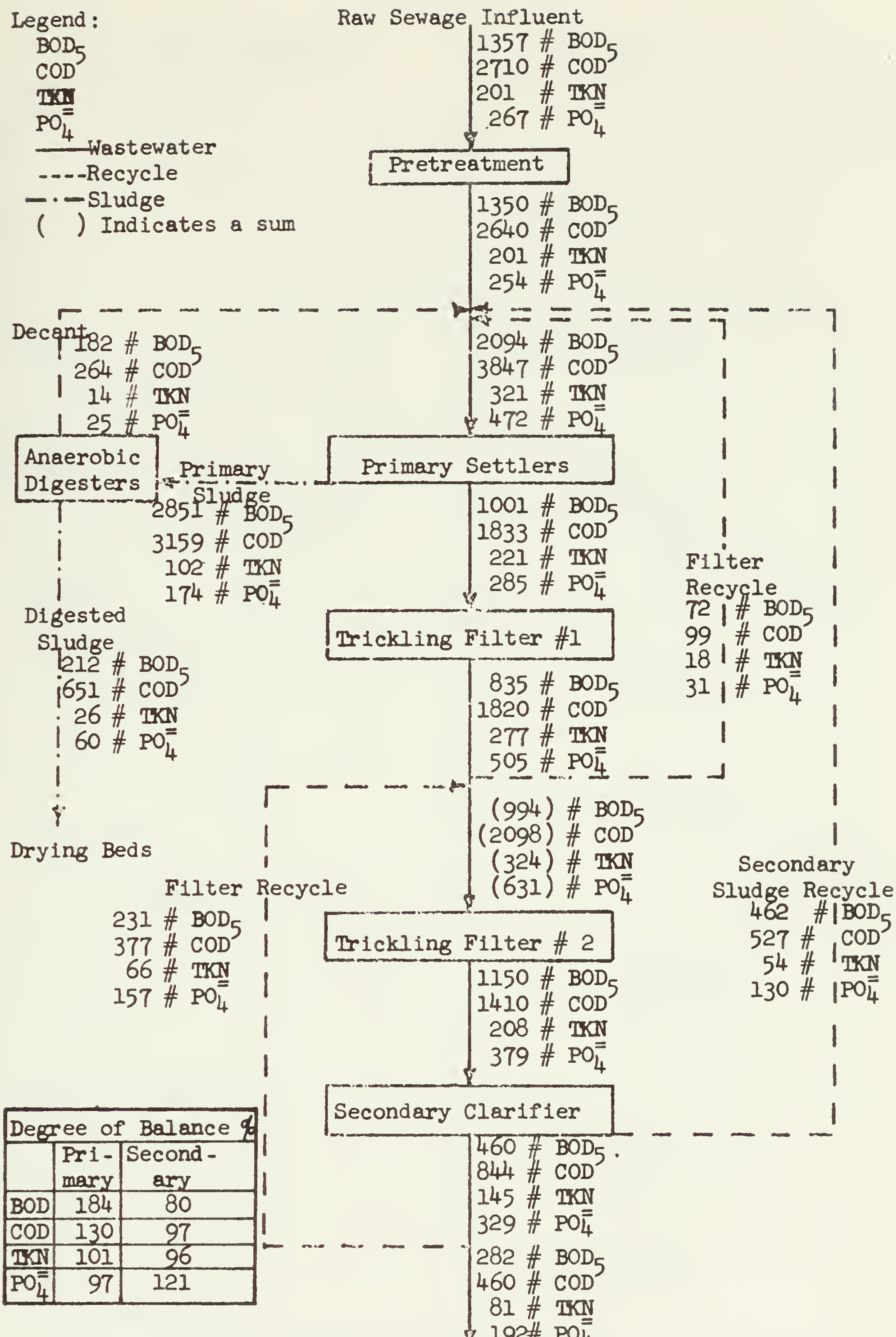
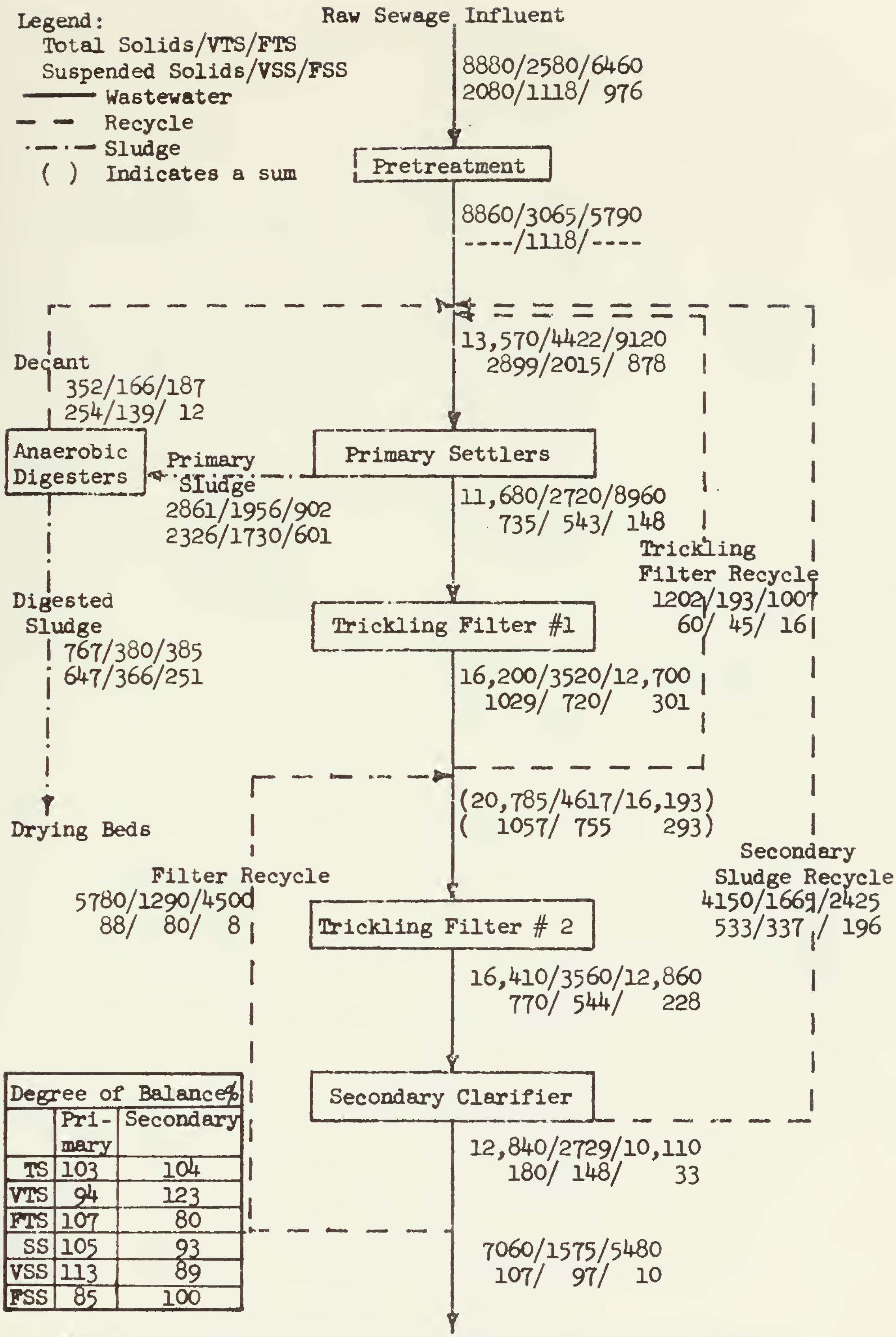


Figure 9. (cont.) Residual Concentrations for Broomfield



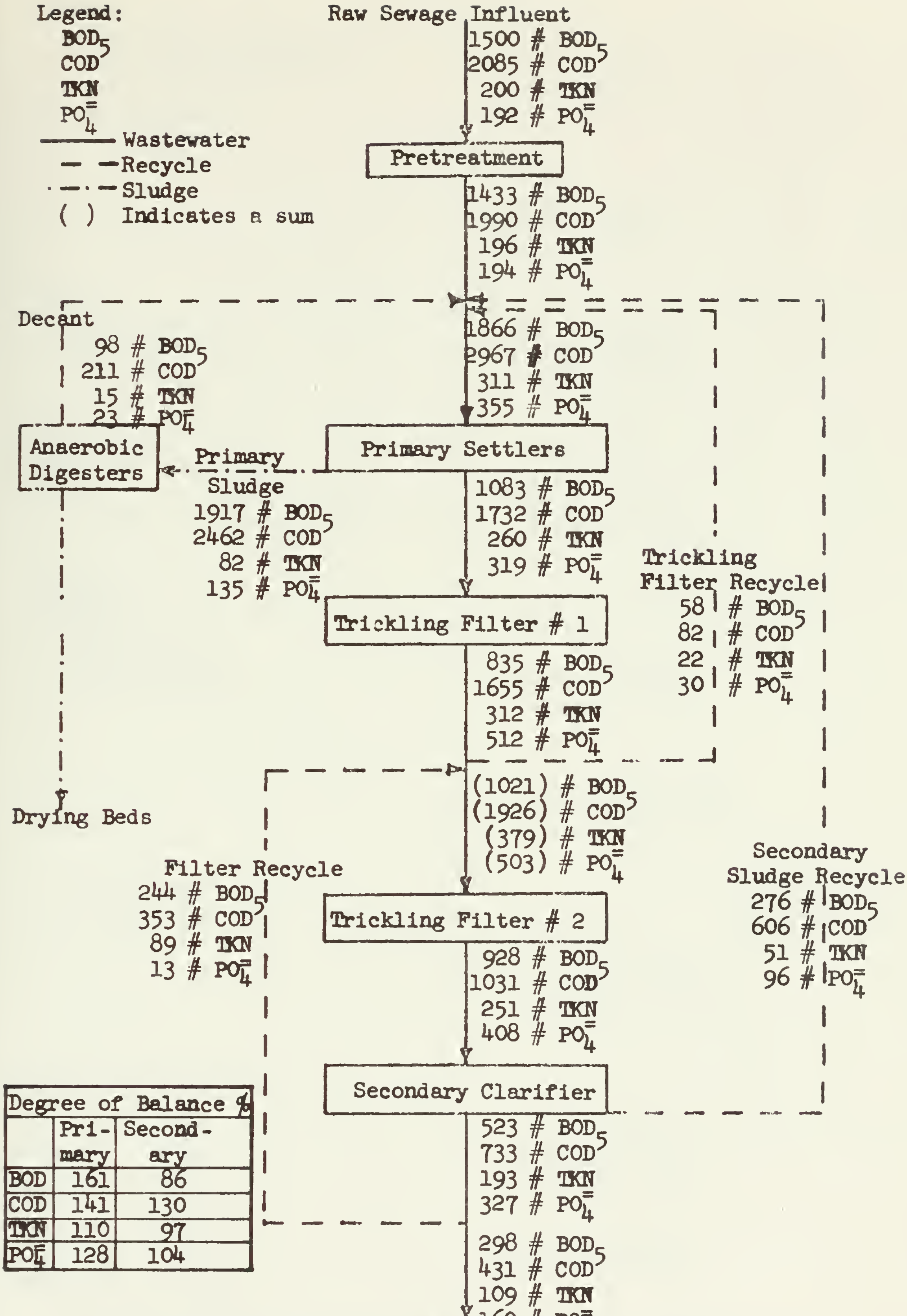
Degree of Balance %	Primary	Secondary
BOD	184	80
COD	130	97
TKN	101	96
$PO_4^=$	97	121

Figure 10. Material Balance for Broomfield on July 21, 1971
All values expressed in pounds per one MG influent flow.



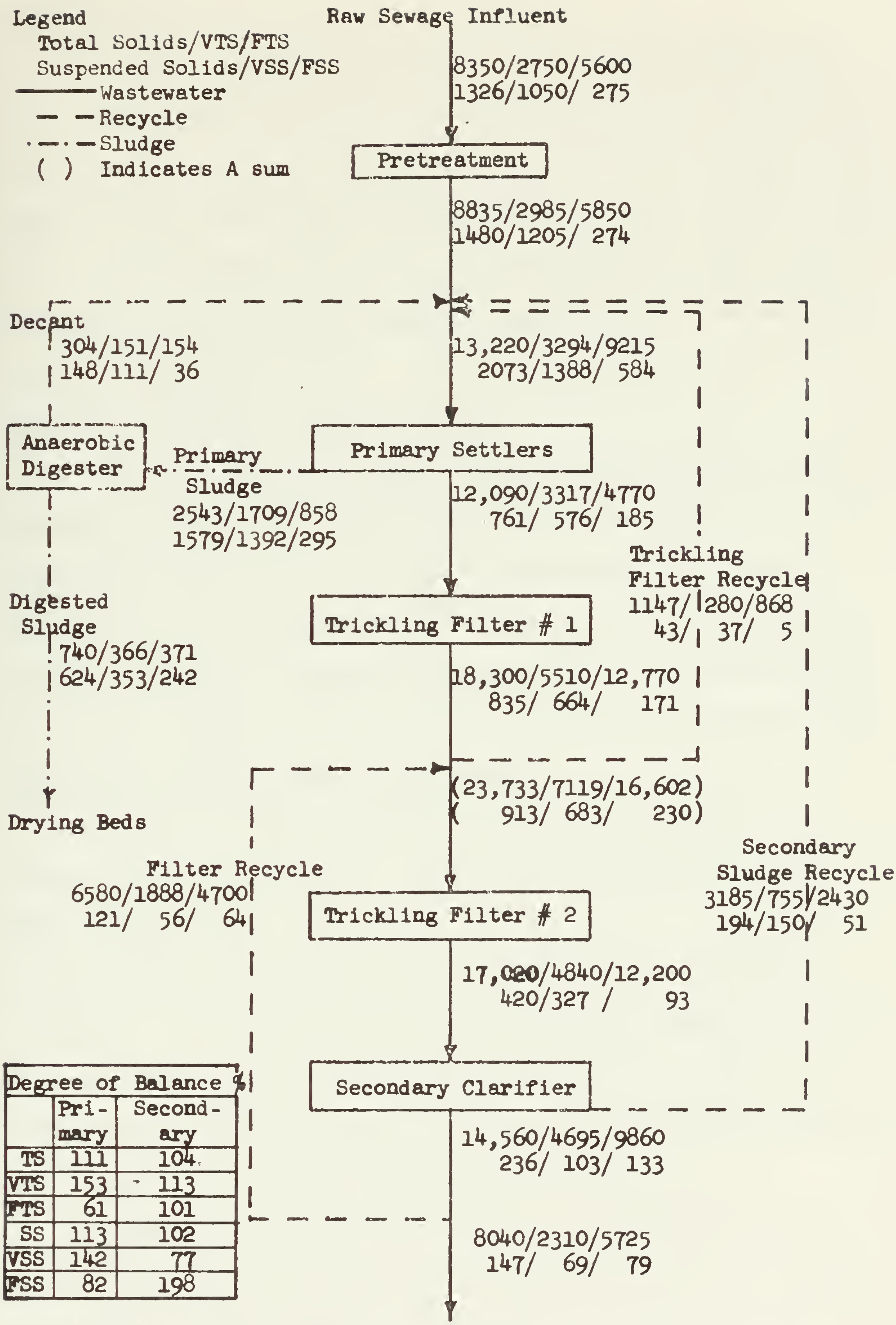
Degree of Balance%		
	Primary	Secondary
TS	103	104
VTS	94	123
FTS	107	80
SS	105	93
VSS	113	89
FSS	85	100

Figure 11. Solids Balance for Broomfield on July 21, 1971
All values expressed in pounds per one MG influent flow.



Degree of Balance %	Primary	Secondary
BOD	161	86
COD	141	130
TKN	110	97
$PO_4^=$	128	104

Figure 12. Material Balance for Broomfield on July 29, 1971
All values expressed in pounds per one MG influent flow.



Degree of Balance %	Primary	Secondary
TS	111	104
VTS	153	113
FTS	61	101
SS	113	102
VSS	142	77
FSS	82	198

Figure 13. Solids Balance for Broomfield on July 29, 1971
All values expressed in pounds per one MG influent flow.

Cost Analysis

Operational costs at the Broomfield plant ran 8.7 cents/1000 gallons even though there were no sludge disposal costs. Treatment costs ran 15.7 cents/1000 gallons when capital costs were added. To remove a pound of BOD_5 and a pound of suspended solids cost 7.6 cents and 7.1 cents respectively. Capital construction costs were lowest/MG in comparison to the other smaller capacity plants. See Appendix IIb for comparisons.

Discussion of Results--Testing Comments

1. The concentration of the primary influent waste parameters showed the Primary #1 was loaded more heavily than Primary #2. See Appendix V. The reason is the same as that given for the Boulder plant. The recycled secondary sludge, a relatively mild waste, is returned principally to Primary #2 diluting the raw sewage influent. This unequal loading is due to inattention to detail in plant design.

Discussion of Results--Concluding Comments

1. BOD_5, COD, and suspended solids showed a high degree of correlation in where they were removed and the magnitude removed. Refer to Figure 9.

2. TKN was essentially removed in the primary settler (via solids) and in the second series trickling filter. TKN was probably oxidized to effect the removal, although nitrate tests were not run on Trickling Filter #2 effluent. Oxidation, due to longer retention periods, probably was the removal mechanism here.

3. Phosphate removed was fairly close to the percent total solids removed indicating that most phosphate was taken out in solid form.

4. Material balances on the primary settlers ranged from 82% to 128% of the material accounted for, except for BOD_5 and COD balances. BOD_5 and COD parameter concentrations of primary sludges appear to give only the order of magnitude of the waste, and hence can result in larger errors in the material balances.

5. Secondary clarifier balances varied from extremes of 80% to 130%, but were generally in the 90% to 105% range.

6. The primary settlers removed 65% of the suspended solids and 50% of BOD_5 and COD. The high removal percentages of BOD_5 and COD were consistent for the two sampling dates and were probably due to the hydraulically underloaded condition of the primary settlers. Secondary treatment removed 80 additional percent of the influent BOD_5, COD and suspended solids. Approximately one half of the 50% of TKN removed by the plant was removed by the primary settlers.

7. The plant removal efficiency was the same for each sampling period even though the weather conditions were very different.

8. The digester supernatent was the most concentrated waste being returned to the plant and constituted 5% to 15% of the total load on the plant. This was based on the assumption that about 50% of the volume of primary sludge removed is returned as digester decant. Mass wise, this is the most critical stream in the plant.

9. Hydraulically, the most critical stream is the secondary sludge recycle returning 1/7 to 1/4 of the total mass load on the plant.

10. One way to increase the efficiency of the primary settlers is to return the recycle of Trickling Filter #1 directly back to the filter. The material balance showed, Figures 10. and 12., that this

stream had only 50-60# suspended solids to remove. This removal could have been accomplished in the secondary clarifiers thereby relieving some of the hydraulic load on the primaries.

BAKER SANITATION DISTRICT SEWAGE TREATMENT PLANT

DENVER, COLORADO

Description of Plant

The Baker Sewage Treatment Plant is a high rate trickling filter plant that is presently being operated at a constant one MGD rate. Raw sewage flows greater than one MGD are bypassed to the Metropolitan Denver plant. The Baker plant is composed of a single, rectangular primary settling tank, a rock media trickling filter, and a single, rectangular secondary clarifier, all in series. Primary effluent, along with part of the trickling filter effluent, is applied to the tricling filter at a constant rate of two MGD. This means that there is about 100% recycle. Secondary effluent is chlorinated prior to being released to Clear Creek.

Secondary sludge is constantly pumped back to the head of the plant and mixed with the raw sewage influent. Primary sludge is collected in the settling tank sump from where it is pumped twice a day to a two stage anaerobic digester. Digester decant is returned to the head of the plant. Digested sludge is dried on sand drying beds prior to removal by the public. Operating conditions are further defined in Appendix I, and a schematic flow diagram is given in Figure 14.

Description of Sampling

Since the influent flow was constant, a fixed sample size was taken every hour, except during the early morning hours when samples were taken at three hour intervals. Sampling was conducted on August 23rd and 27th from 9:00 AM to 9:00 AM the following morning. One error was made with the secondary clarifier effluent on

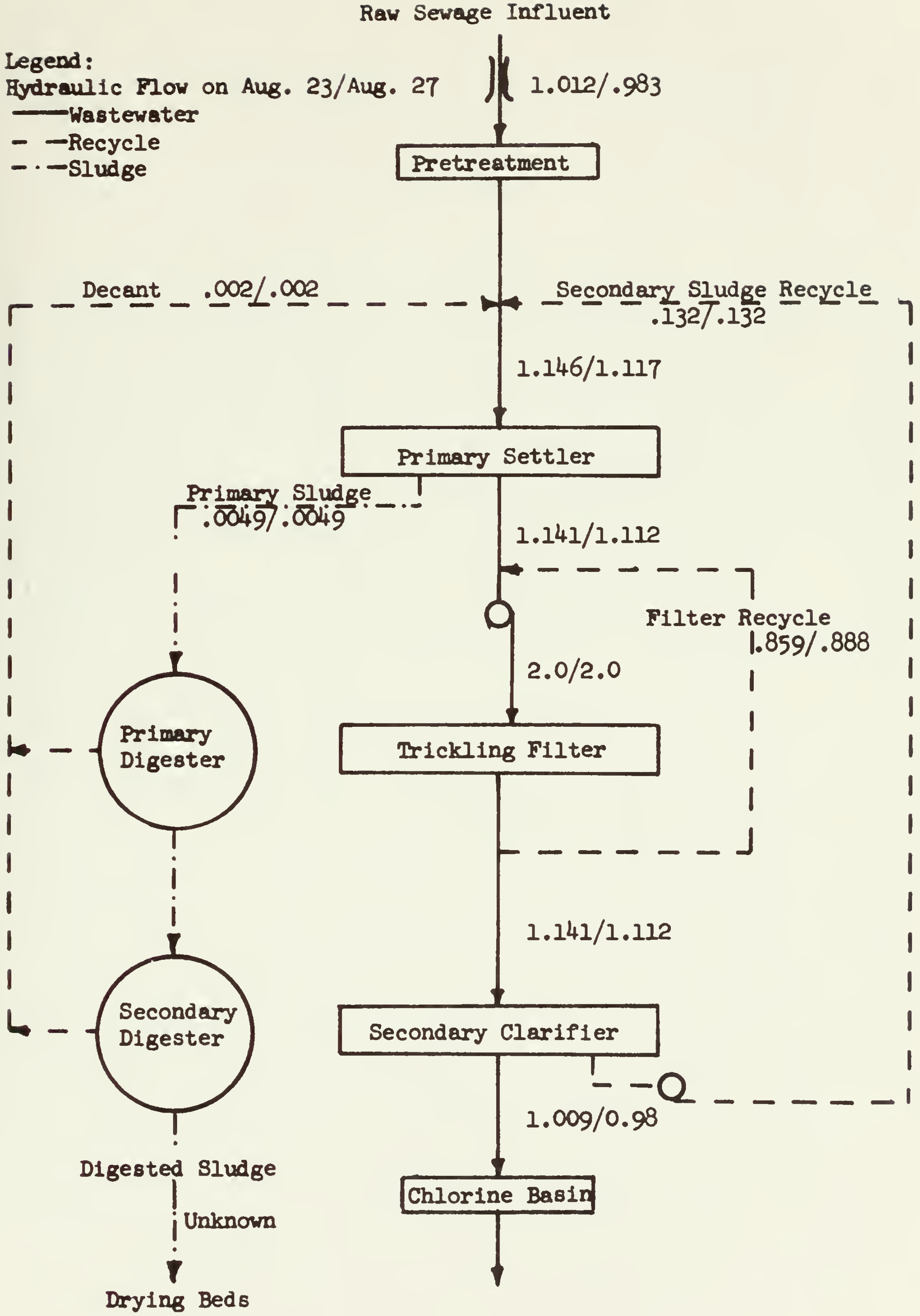


Figure 14. Hydraulic Flow Diagram for Baker
All values expressed in million gallons per day.

August 23rd. One grab sample of secondary sludge recycle was accidentally mixed with clarifier effluent. Test data was altered as described in the discussion of results part of this section.

TABLE III

Plant/Unit Removal Efficiencies for Baker Sewage Treatment Plant													
Para-meter --- Test-ing Period	Plant	Primary Settler				Trickling Filter				Secondary Clarifier			
	Inf. mg/L	Pri. Inf. mg/L	Pri. Eff. mg/L	% of Pri. Inf. Removed	% of Plant Inf. Removed	Tri. Fil. Inf. mg/L	Tri. Fil. Eff. mg/L	% of T. F. Inf. Removed	% of Plant Inf. Removed	Sec. Inf. mg/L	Sec. Eff. mg/L	% of Sec. Inf. Removed	% of Plant Inf. Removed
BOD-I	243	243	95	61	61	142	70	51	71	70	71	-1.5	71
BOD-II	140	169	132	22	6	100	80	20	43	80	37	54	74
COD-I	387	398	259	35	33	171	123	28	68	123	108	12	72
COD-II	338	352	233	34	31	166	145	13	57	145	82	43.5	76
TKN-I	27.6	28.3	26.7	5.7	3.3	24.7	22.4	9	19	22.4	20.7	7.6	25
TKN-II	26.4	27.1	25.7	5	2.7	22.9	21.2	7.4	19.7	21.2	20.1	5	24
PO_4-I	34	38.7	38.7	0	-14	34.7	30	13.5	12	30	33.9	-13	.3
PO_4-II	31.5	33	27.5	17	12.7	27	28.5	-5.5	9.6	28.5	24.5	14	22.3
TS-I	1235	1255	1234	1.7	0	1200	1226	-2	.7	1226	1162	5	6
TS-II	1384	1393	1229	12	11	1267	1249	1.5	9.8	1249	1152	7.8	16.8
VTS-I	362	357	295	17.4	18.5	249	238	4.4	34	238	217	9	40
VTS-II	434	380	234	38.4	46	313	307	2	29.3	307	223	27.4	48.6
FTS-I	873	898	939	-4.5	-7.6	951	988	-3.9	-13	988	944	4.5	-8
FTS-II	947	1013	995	1.8	-5	955	942	1.4	.5	942	929	1.4	2
SS-I	155	172	93	46	40	110	96	13	38	96	80	17	48.4
SS-II	164	173	85	51	48.2	68	69	-1.5	58	69	31	55	81
VSS-I	132	144	77	46.6	41.7	72	66	8	50	66	57	13.6	57
VSS-II	138	142	70	51	49.3	52	53	-2	61.6	53	26	51	81
FSS-I	22	28	16	43	27	38	30	21	-36	30	23	23.3	-4.5
FSS-II	25	31	15	51.6	40	16	15	6	40	15	5	67	80

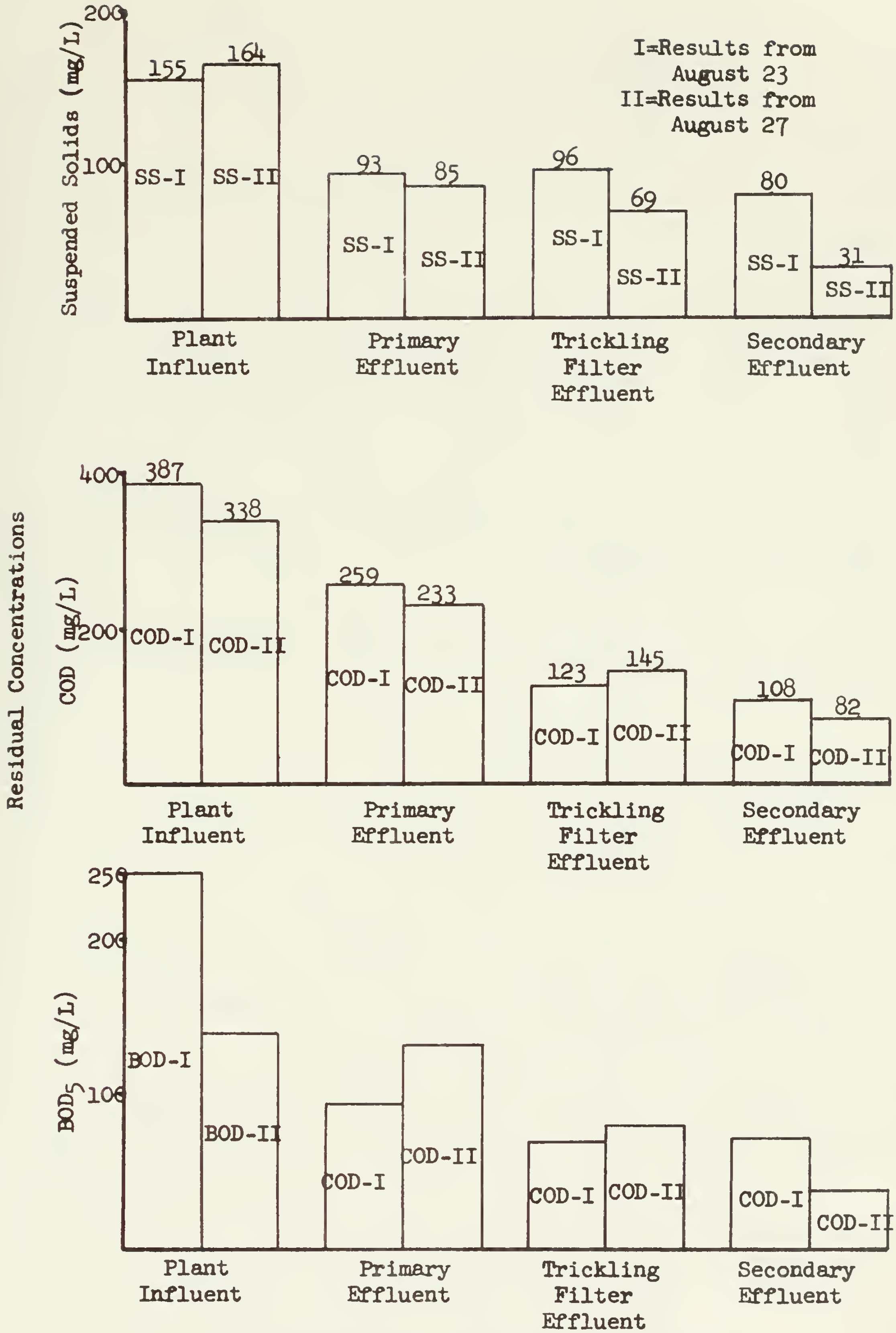


Figure 15. Residual Concentrations for Baker

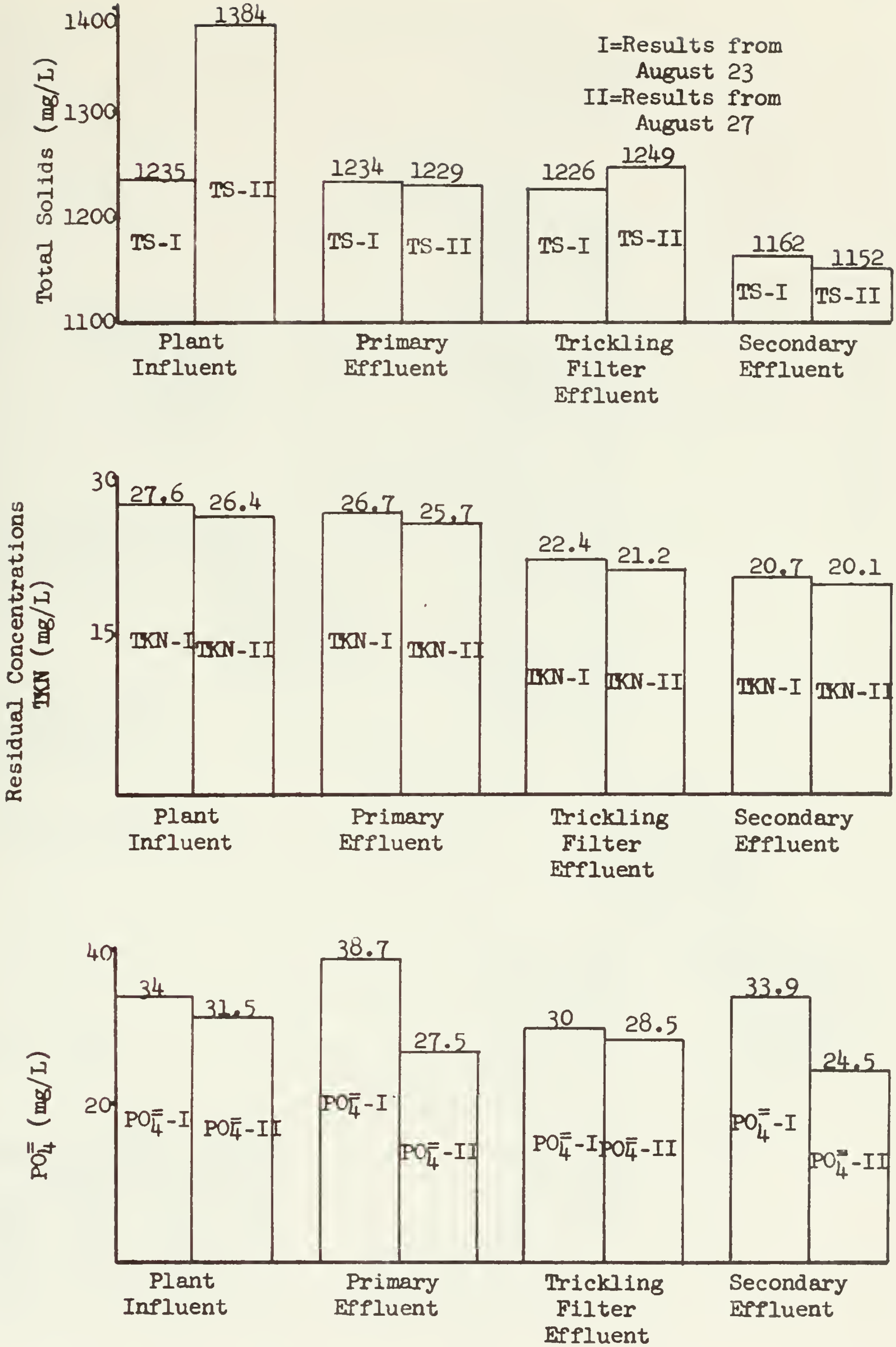
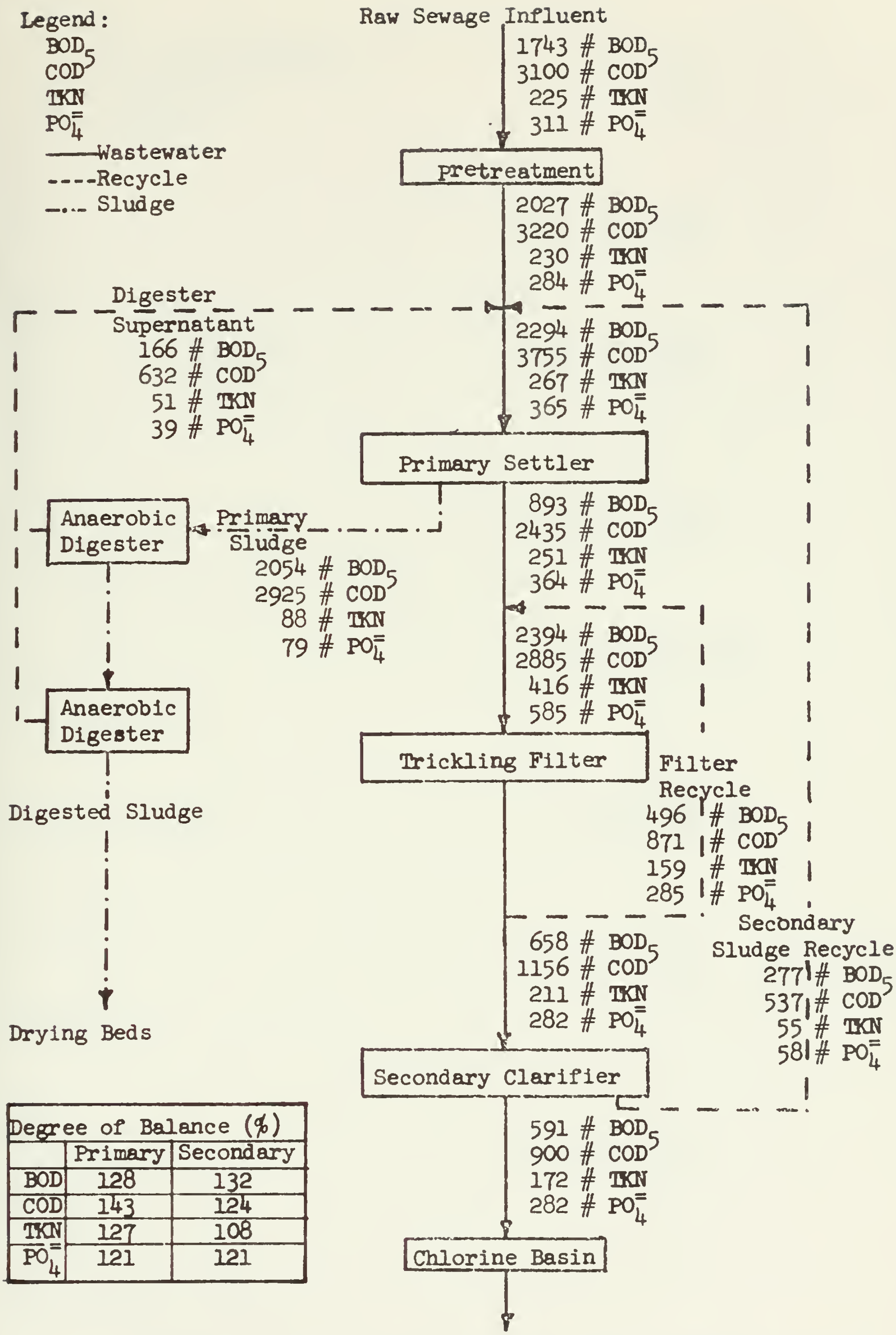
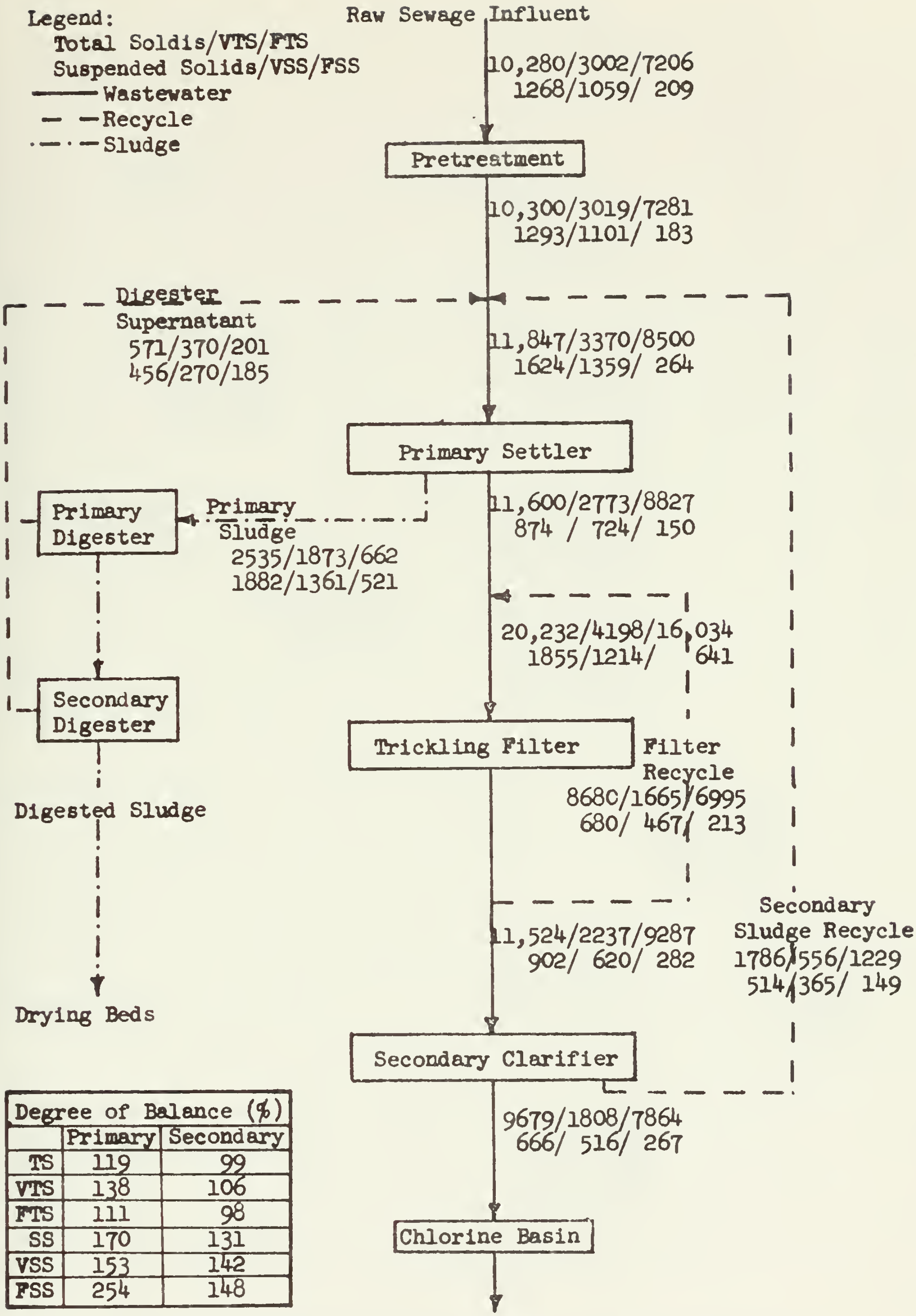


Figure 15. (cont.) Residual Concentrations for Baker



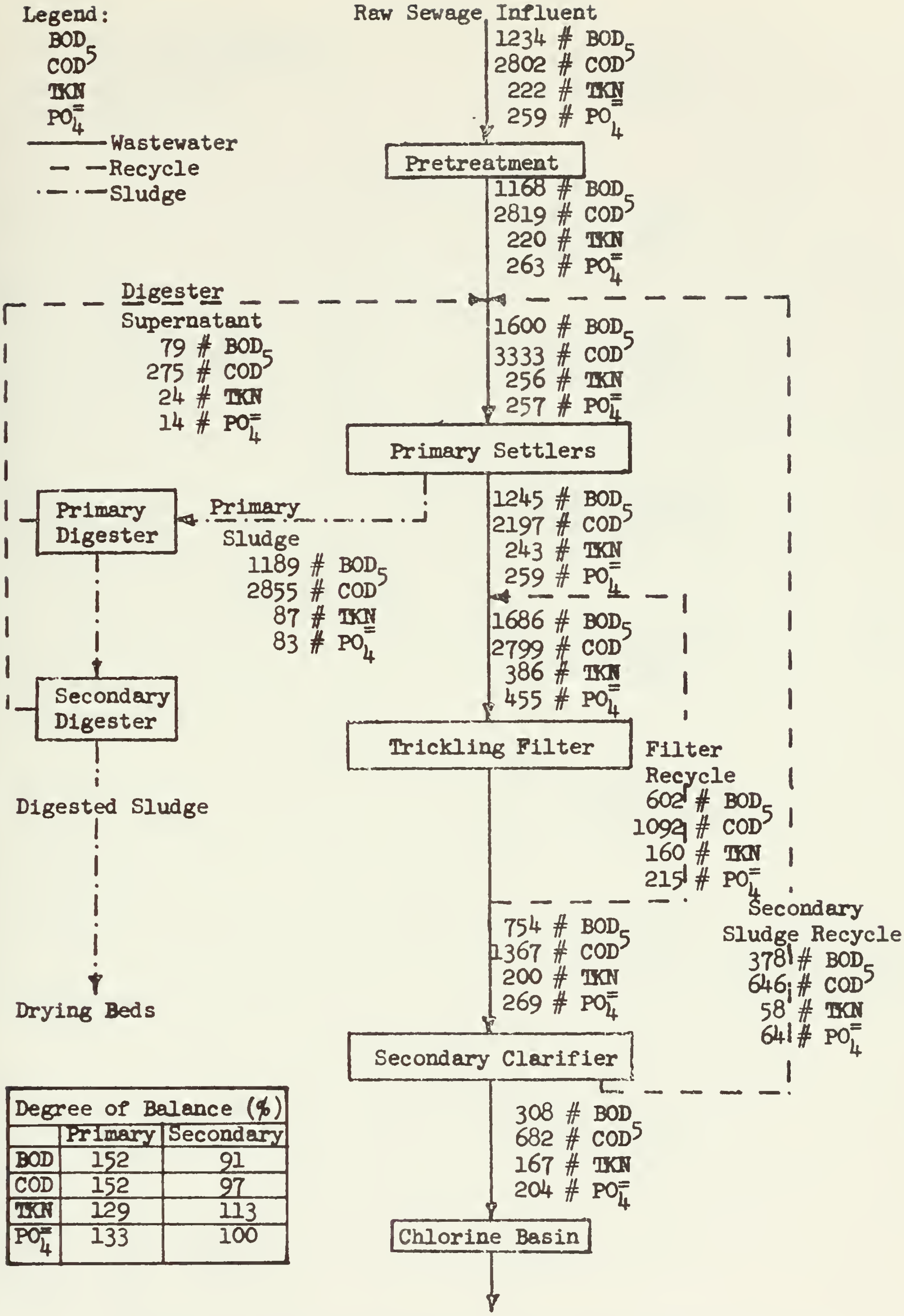
Degree of Balance (%)		
	Primary	Secondary
BOD	128	132
COD	143	124
TKN	127	108
$PO_4^{=}$	121	121

Figure 16. Materials Balance for Baker on Aug. 23, 1971
All values expressed in pounds per one MG influent flow.



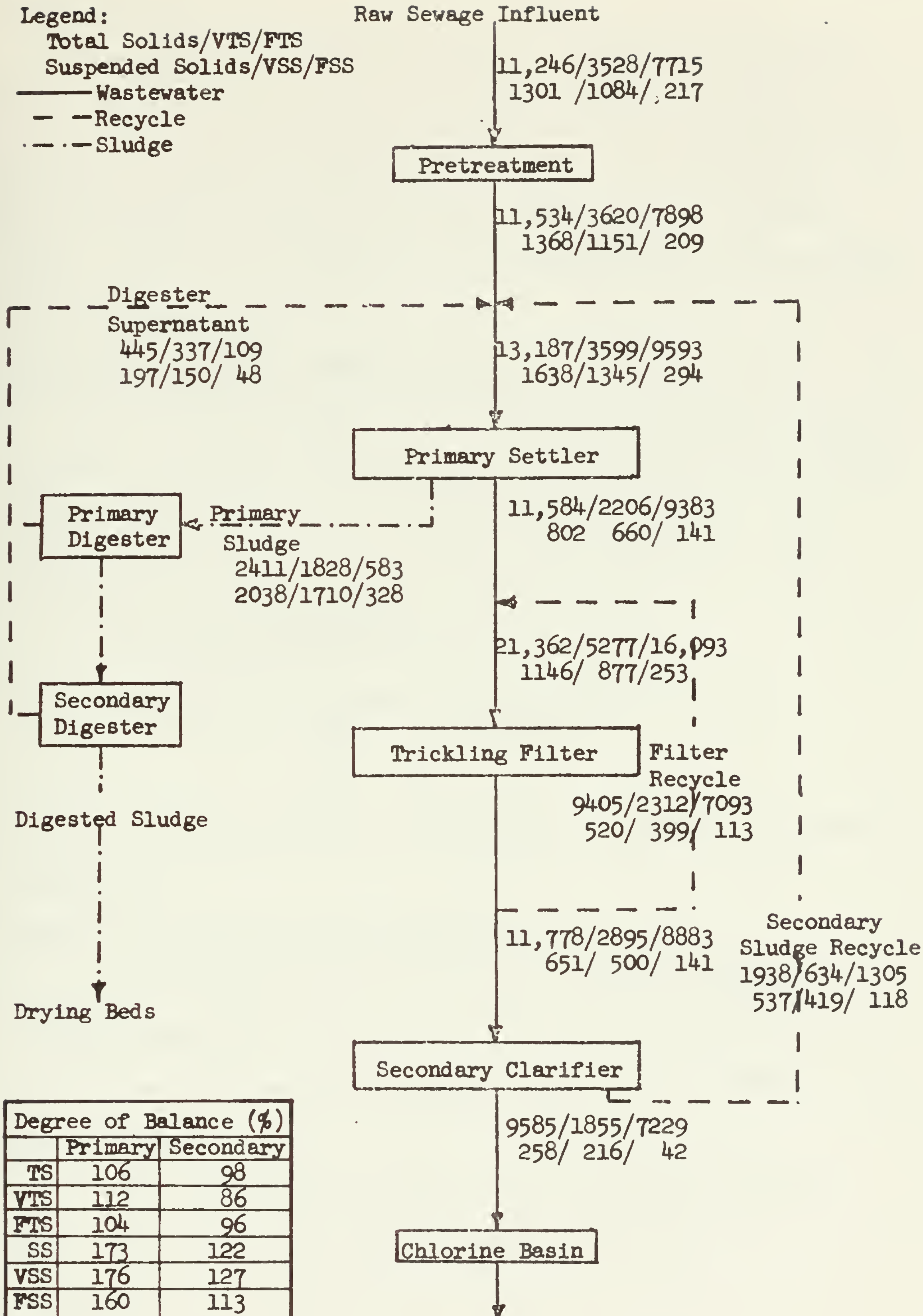
Degree of Balance (%)		
	Primary	Secondary
TS	119	99
VTS	138	106
FTS	111	98
SS	170	131
VSS	153	142
FSS	254	148

Figure 17. Solids Balance for Baker on Aug. 23. 1971
All values expressed in pounds per one MG influent flow.



Degree of Balance (%)		
	Primary	Secondary
BOD	152	91
COD	152	97
TKN	129	113
$PO_4^=$	133	100

Figure 18. Materials Balance for Baker on Aug. 27, 1971
All values expressed in pounds per one MG influent flow.



Degree of Balance (%)		
	Primary	Secondary
TS	106	98
VTS	112	86
FTS	104	96
SS	173	122
VSS	176	127
FSS	160	113

Figure 19. Solids Balance for Baker on Aug. 27, 1971
All values expressed in pounds per one MG influent flow.

Cost Analysis

Operational Treatment costs ran 9.5 cents/1000 gallons, and total treatment costs ran 12.5 cents/1000 gallons. Costs/# of pollutant removed were generally higher than other plants because the # of pollutant removed/MG was lower for this plant. See Appendix IIIa. Capital construction costs and operational costs per treatment unit were not available.

Discussion of Results--Testing Comments

1. The error made with the secondary clarifier effluent sample during the August 23rd sampling period was corrected for by subtracting from test results of the secondary clarifier effluent sample, 1/24 of the concentration of the secondary sludge recycle sample.

X = true concentration
Y = tested secondary effluent concentration

X x 24 aliquots + Secondary Sludge Recycle x 1 aliquot
Parameter Concentration

= Y x 25 aliquots.

The "X" value calculated was the concentration used in all subsequent calculations.

Discussion of Results--Operating Comments

1. The digester decant pumped from the primary digester was returned irregularly. Consequently, the volume of flow was hard to estimate, and the loading due to this stream should be used only with this knowledge in mind.

2. No digested sludge samples have been available between August and December; therefore, this part of the analysis is incomplete.

Discussion of Results--Concluding Comments

1. Data indicates that the trickling filter removed some suspended solids and TKN during the first study period, but otherwise passed total solids, suspended solids, TKN, and $PO_4^=$ through the filter with virtually no change, within material balance accuracy. See Figures 16. and 18. During the two testing periods, secondary treatment removed 69% and 75% of the BOD_5, and 63% and 69% of the COD, respectively.

2. Again, the major imbalances occurred around the primaries pointing out testing and flow metering difficulties. Even though the volume of primary sludge removed was thought to be accurate, analysis results were not better than other plants studied.

3. The concentration of the secondary sludge recycled was more concentrated, and the rectangular tank raking mechanism returned the sludge with a greater consistency in concentration than plants with circular clarifiers and collection mechanisms. The secondary sludge is more frequently deposited in the clarifier collection sump in a rectangular tank.

4. The nature of the digester decant recycled indicates that the digester isn't operating correctly, or that the decant is being removed at a non-advantageous place. The percent volatile solids in the primary sludge removed as 74% and 76% for the two sampling periods. The percent volatile solids in the returned decant was 64% and 76% respectively. See Appendix VI for data. Compare this with the decant from the Broomfield digesters which were 47% and 49% for two different sampling days. This indicates the digesters at

Baker are not being used to their highest capacity, and consequently, reduce the efficiency of the entire treatment plant.

5. The removal efficiencies of BOD_5, COD , and suspended solids for each unit in a trickling filter plant, when connected together, form approximately a straight line, indicating that each unit removes about the same proportion of influent load. See Figure 15. Phosphate removal closely followed total solids removed indicating the $PO_4^{=}$ was removed in the solid form. TKN removal was remarkably consistent for the two samples taken. Secondary treatment removed 31.5% of the TKN during each sampling period. This 31.5% removal was much less than the 75% and 58% TKN removals recorded for secondary treatment at the Broomfield plant. The higher broomfield removals can be attributed to the two stage trickling filter configuration which provides for longer retention times with more biologic action.

COLORADO SPRINGS SEWAGE TREATMENT PLANT

COLORADO SPRINGS, COLORADO

Description of Plant

The Colorado Springs Sewage Treatment Plant is a high rate trickling filter plant which is operating above design capacity. Design flow is 12 MGD for the trickling filters and 24 MGD for the primary settlers, and the plant is presently processing about 23 MGD. Being built in parallel with the existing plant is a 30 MGD activated sludge plant to go into operation in August of 1973. The existing plant consists of the following units: three parallel primary settlers, three parallel covered trickling filters, and three parallel secondary clarifiers. A flow diagram of this plant is included in Figure 20., and operating variables are given in Appendix I.

A unique feature of this plant is the sludge handling process, the Porteous heat treatment process first used in England (17). The sludge undergoes pressure/heat treatment prior to being applied to a vacuum filter. The Porteous process eliminates the need for chemical conditioning prior to vacuum filtration. In detail, this process passes primary or holding tank sludge through the first half of a heat exchanger to heat the sludge up to about 120°F. The heated sludge enters a pressure tank where superheated steam is added. The sludge is cooked under pressure and heat for about 1.2 hours. A float valve controls the release of treated sludge to the hot half of the heat exchanger. A closed loop water circulation system transfers heat from the hot, treated sludge to the cold, incoming sludge. The treated sludge enters a decanting tank where it is

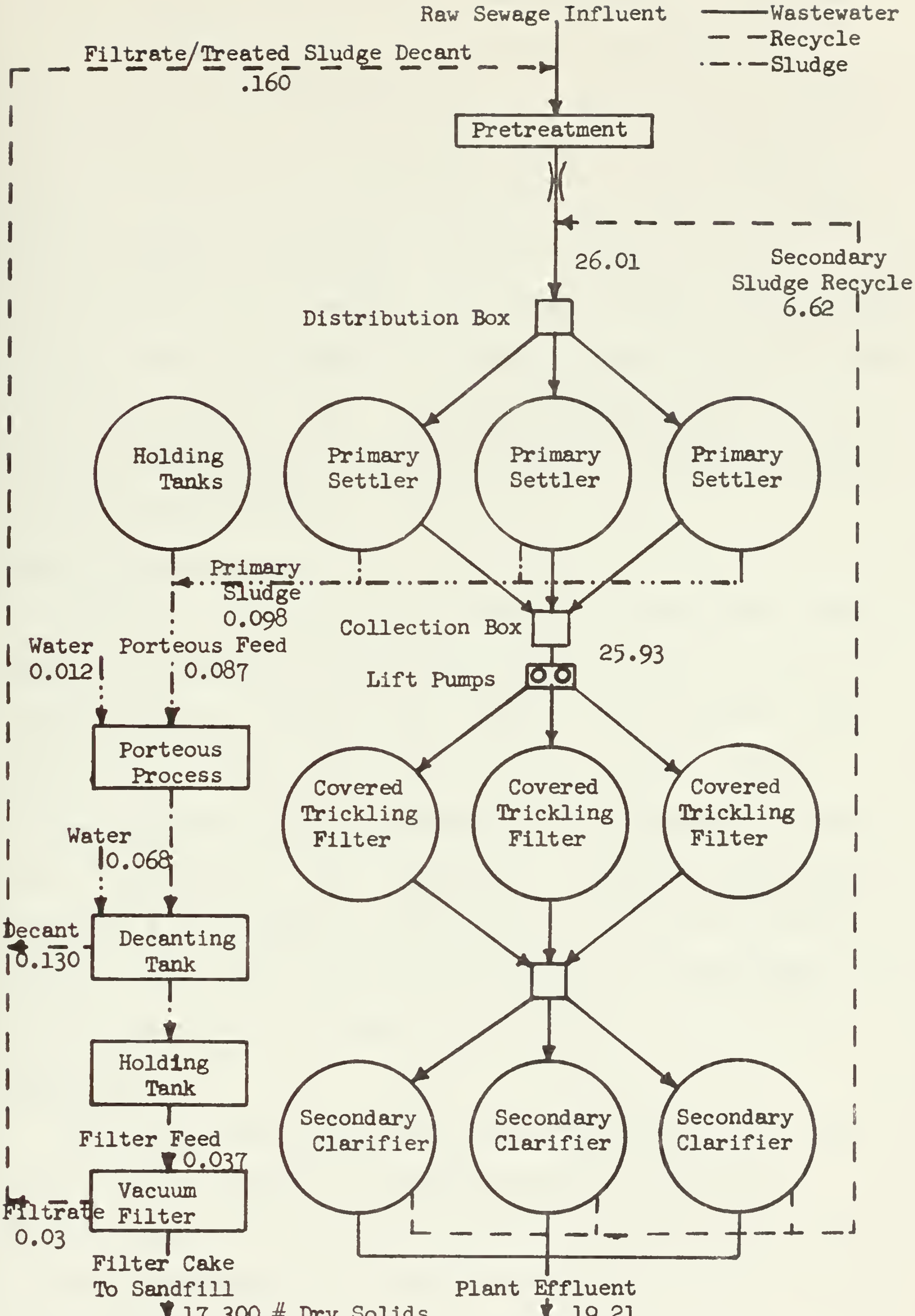


Figure 20. Hydraulic Flow Diagram for Colorado Springs on Oct.28
All Flow Values are in Million Gallons per Day.

further cooled by tertiary treated water injected into the treated sludge. The purpose of this cooling water is to increase the ability of the treated sludge to settle. Decant from this cooling tank is recycled back to the head of the plant. The concentrated sludge is transferred to a holding tank to await vacuum filtration. The concentrated, treated sludge exhibits excellent filtration characteristics. Total solids in the filter cake have been produced as high as 50% at this plant. The high filtering ability is believed due to the breakdown of the water holding chemical bonds in the raw sludge. The filter cake is hauled to landfill. A schematic flow diagram is given in Figure

Description of Sampling

Because of the overloaded nature of the treatment plant, only the sludge processing and related wastewater streams of the plant were investigated. Composited grab samples of the wastewater were taken every two hours. Sample points were: 1) one of the five influent raw sewage mains, 2) primary influent, 3) primary effluent, and 4) plant effluent. The vacuum filter is operated approximately five hours a day. Samples of filter feed, filter cake and filtrate were taken every half hour during this period. All other samples of the Porteous process were taken every two hours.

Efficiency

Efficiency evaluation of the sewage treatment plant will only involve primary and plant removal efficiencies. The Porteous process is evaluated in terms of the pounds of material applied and how much of that material is removed for disposal. A pounds basis is used for this analysis.

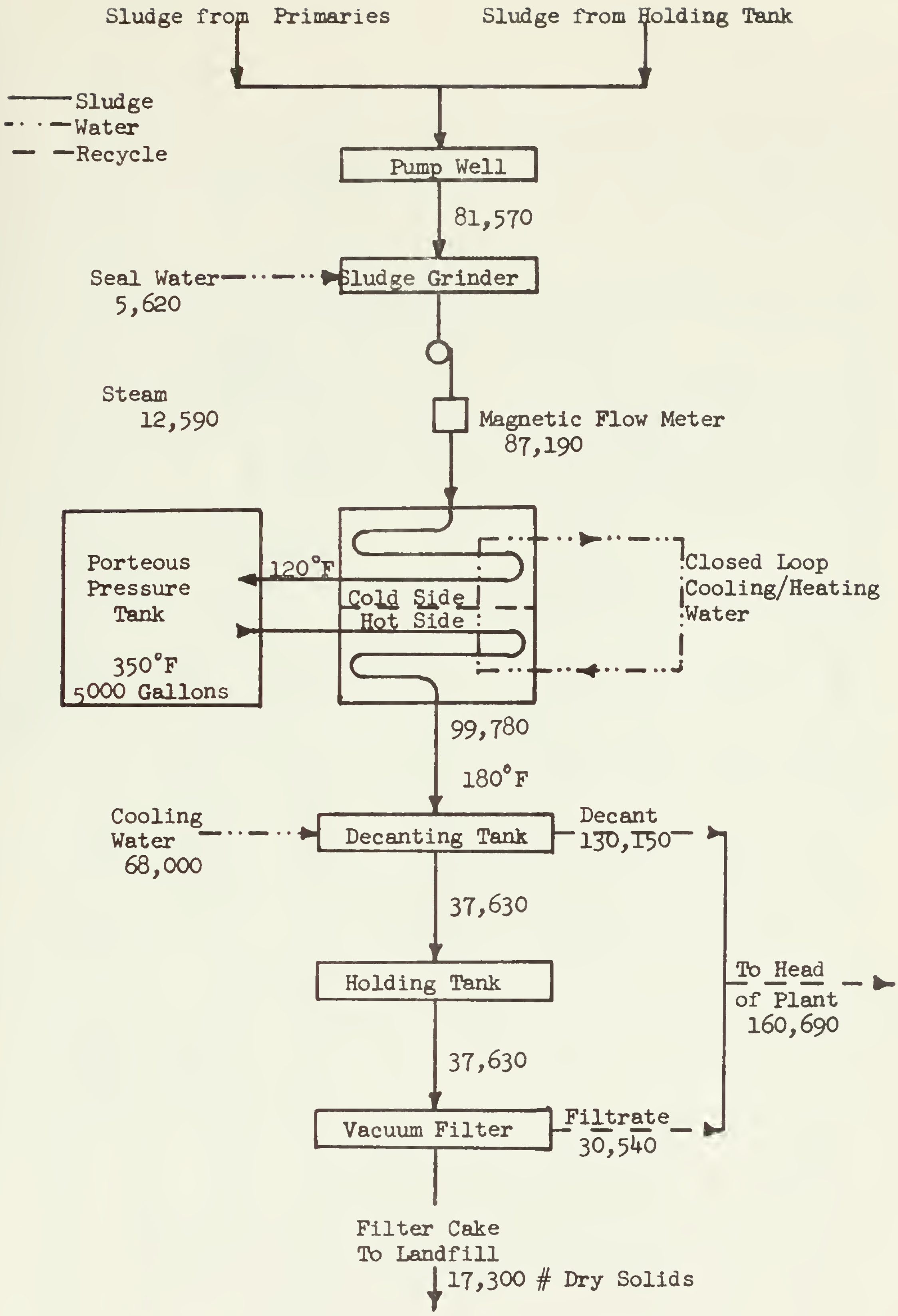


Figure 21. Porteous Process Hydraulic Flow Diagram
All values are in Gallons per Day.

TABLE IV

Plant/Unit Removal Efficiencies for Colorado Springs Sewage Treatment Plant

Parameter	Plant	Primary Settlers				Secondary Clarifiers		Porteous Feed	After Decant	% Remaining After Decant Tank	% Removed by Decant Tank	After Vacuum Filter #/MGD Plant Inf.	% Removed by Vacuum Filter	% Remaining After Vacuum Filter
	Inf. mg/L	Pri. Inf. mg/L	Pri. Eff. mg/L	% of Pri. Inf. Removed	% of Plant Inf. Removed	Sec. Eff. mg/L	% of Plant Inf. Removed	#/MGD Plant Inf.	#/MGD Plant Inf.					
BOD_5	225	273	193	29.3	14	99	56	695	495	71	29	455	92	65
COD	442	538	291	46	34	191	57	1799	1343	81.5	18.5	1094	81.5	61
TKN	28.2	32	28	12	1	24	13.5	55	26	47	53	11	42	20
$PO_4^{=}$	30.5	39	34	14	-10	35	-13	59	35	59	41	41	-17	69.5
TS	647	861	682	21	-5.4	590	9	1287	1061	82	18	901	85	70
VTS	343	482	232	52	32	158	54	998	744	14.5	25.5	617	83	62.5
FTS	304	379	449	-32	-48	429	-41	288	317	110	-10	284	90	99
SS	171	242	99	59	42	60	65	1102	980	89	11	980	99+	89
VSS	131	199	79	60	40	51	61	953	729	76.5	23.5	729	99+	76.5
FSS	40	43	20	53.5	50	9	77.5	149	252	169	-69	252	99+	169

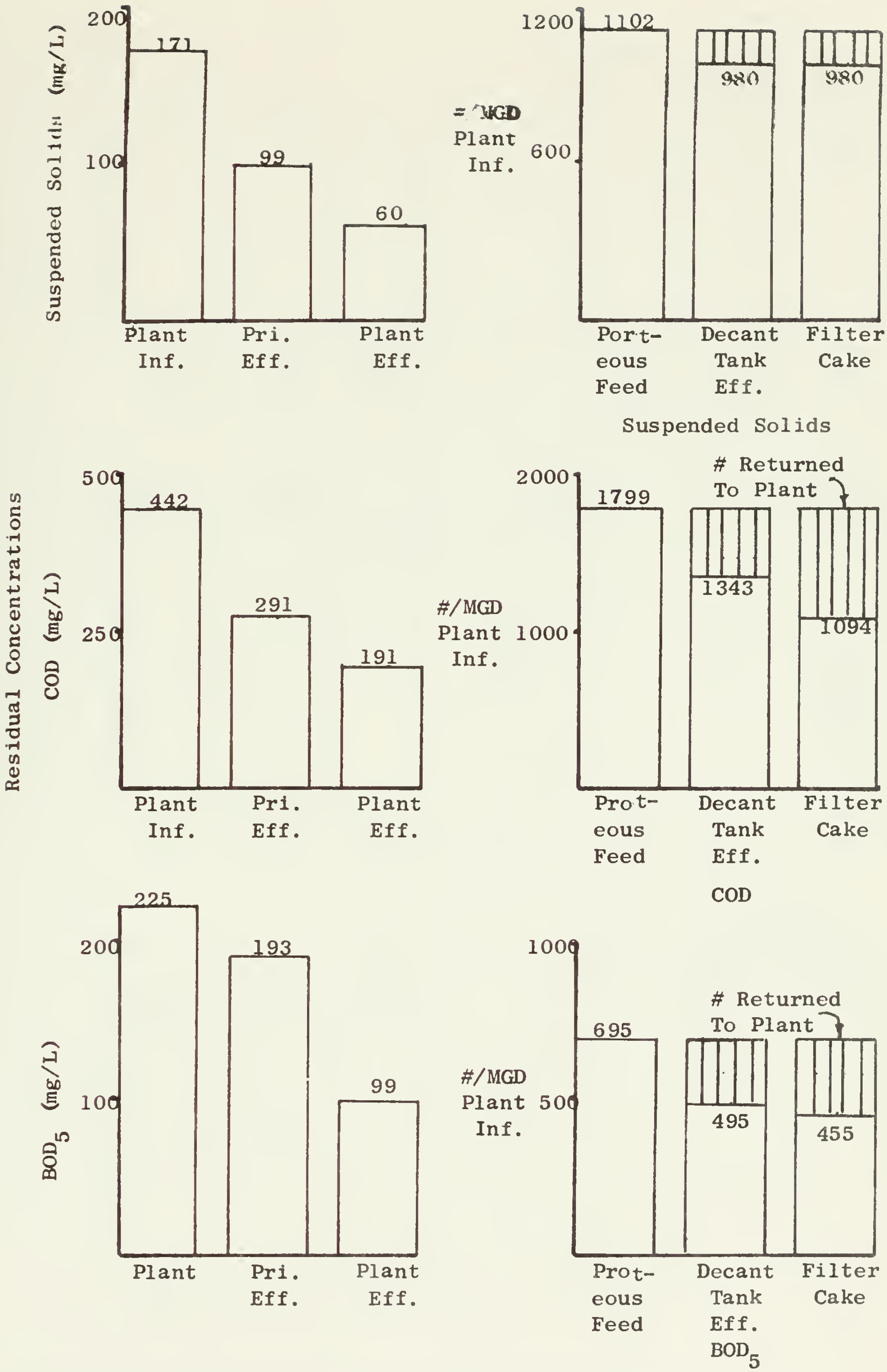


Figure 22. Residual Concentrations for Colorado Springs

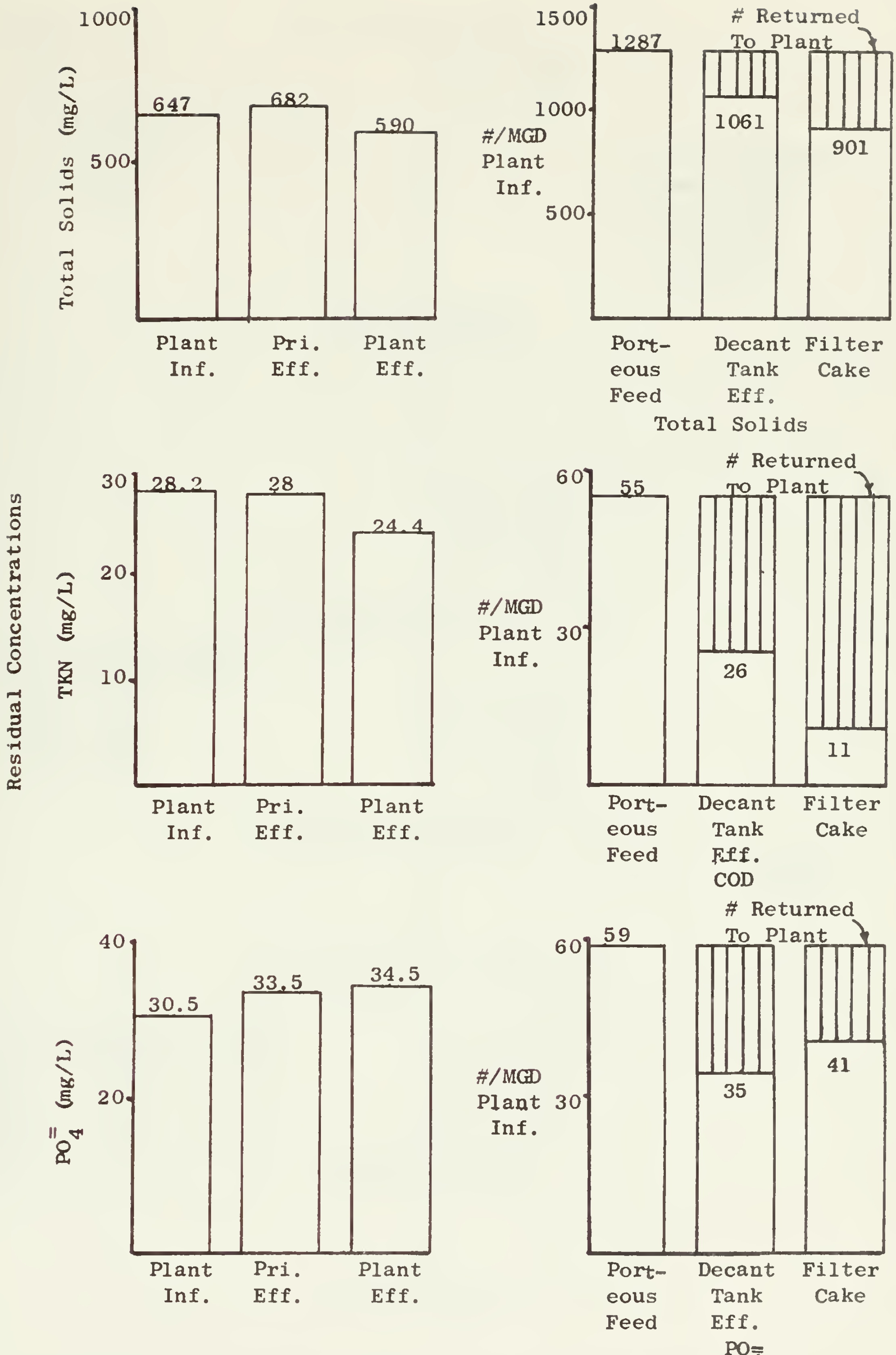
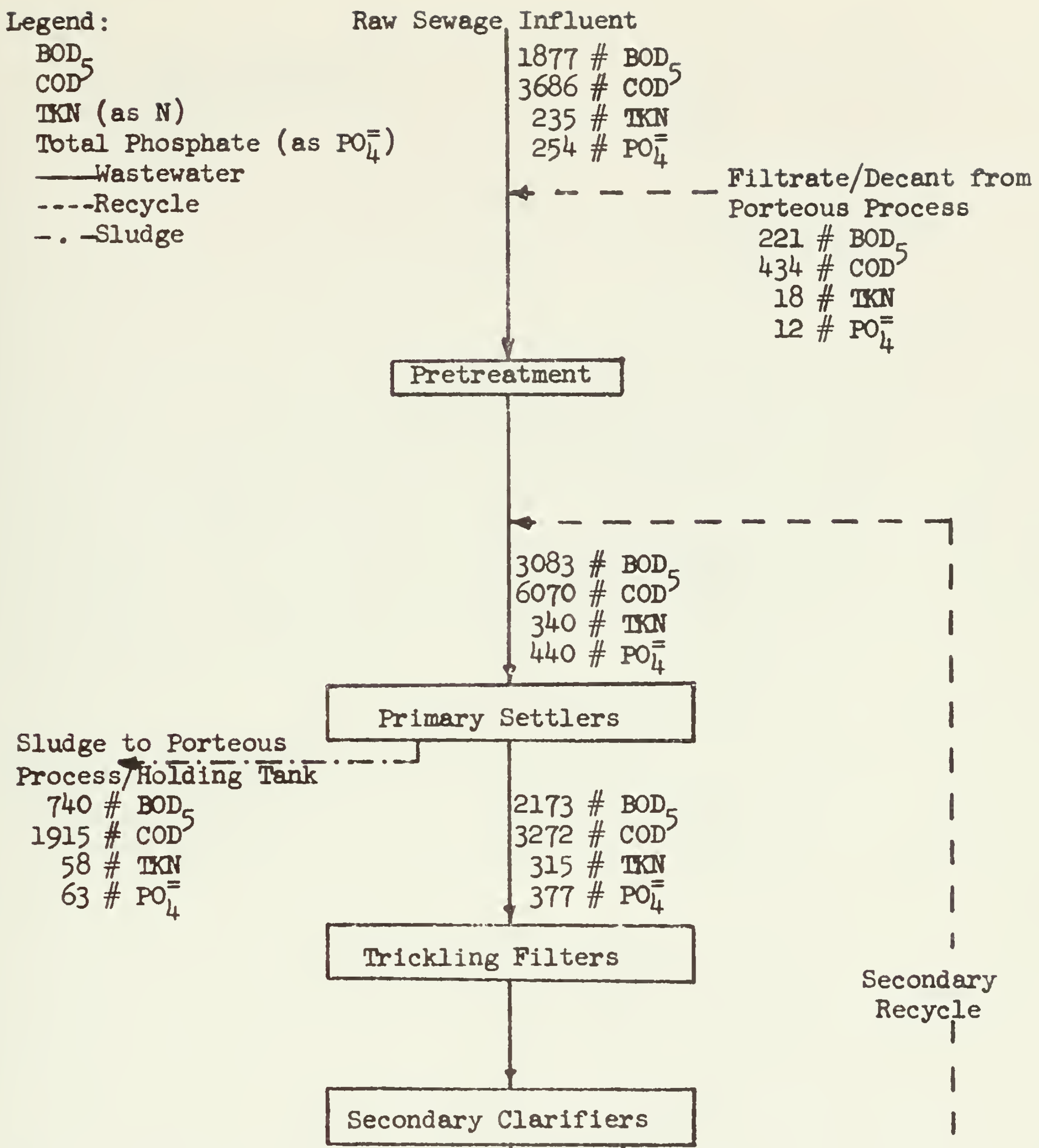
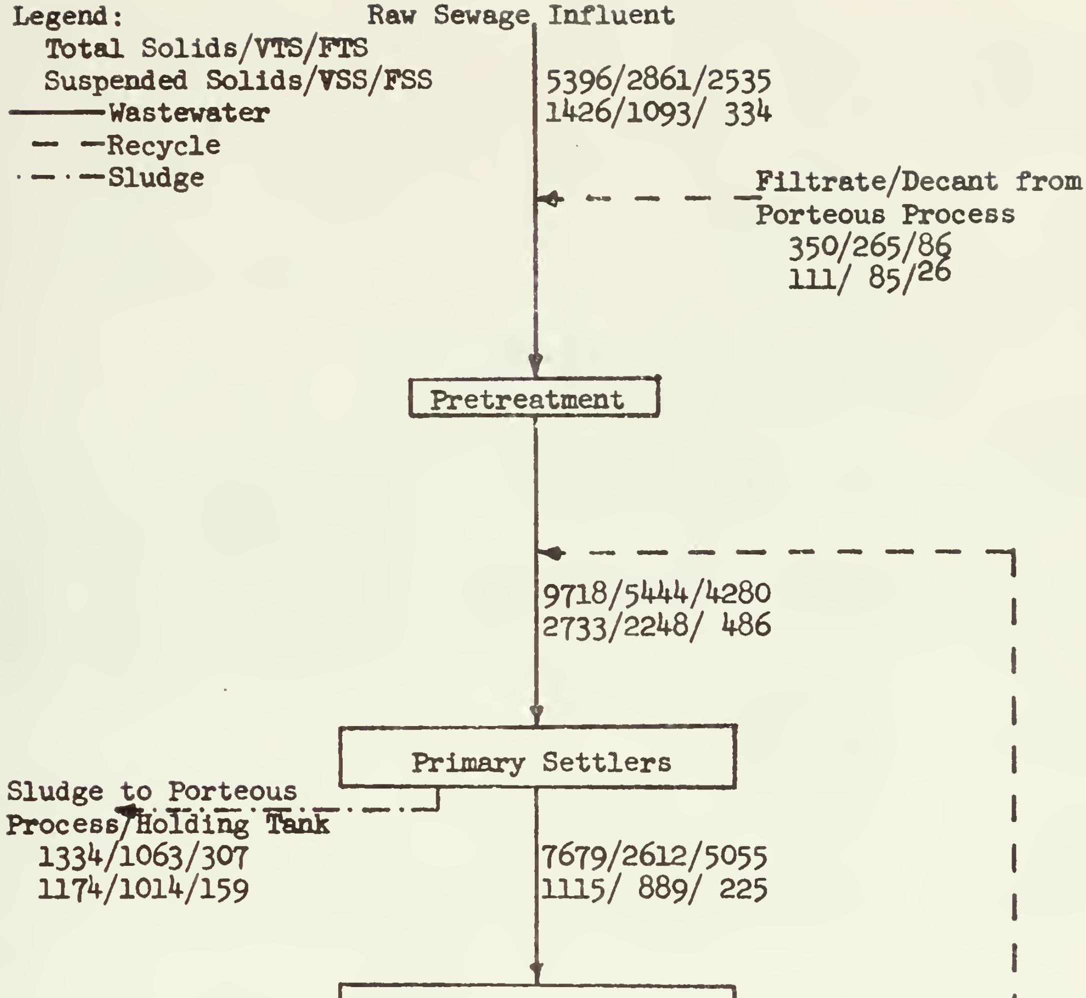


Figure 22. Residual Concentrations for Colorado Springs



Degree of Balance (%)	
	Primary
BOD	95
COD	86
TKN	110
$PO_4^=$	100

Figure 23. Material Balance for Colorado Springs on Oct. 28, 1971
All values expressed in pounds per one MG influent flow.



Degree of Balance (%)	
	Primary
TS	93
VTS	68
FTS	125
SS	84
VSS	85
FSS	79

Figure 24. Solids Malance for Colorado Springs on Oct. 28, 1971
All values expressed in pounds per one MG influent flow.

Legend:
- BOD_5
- COD
- TKN (as N)
- Total Phosphate (as $PO_4^{=}$)
- — · — Sludge
- — — Recycle
- ——— Water
- ( ) Indicates a sum

Degree of Balance (%)			
	Porteous	Decant	Filter
BOD	103	94	--
COD	95	99	88
TKN	102	73	54
$PO_4^{=}$	76	98	126

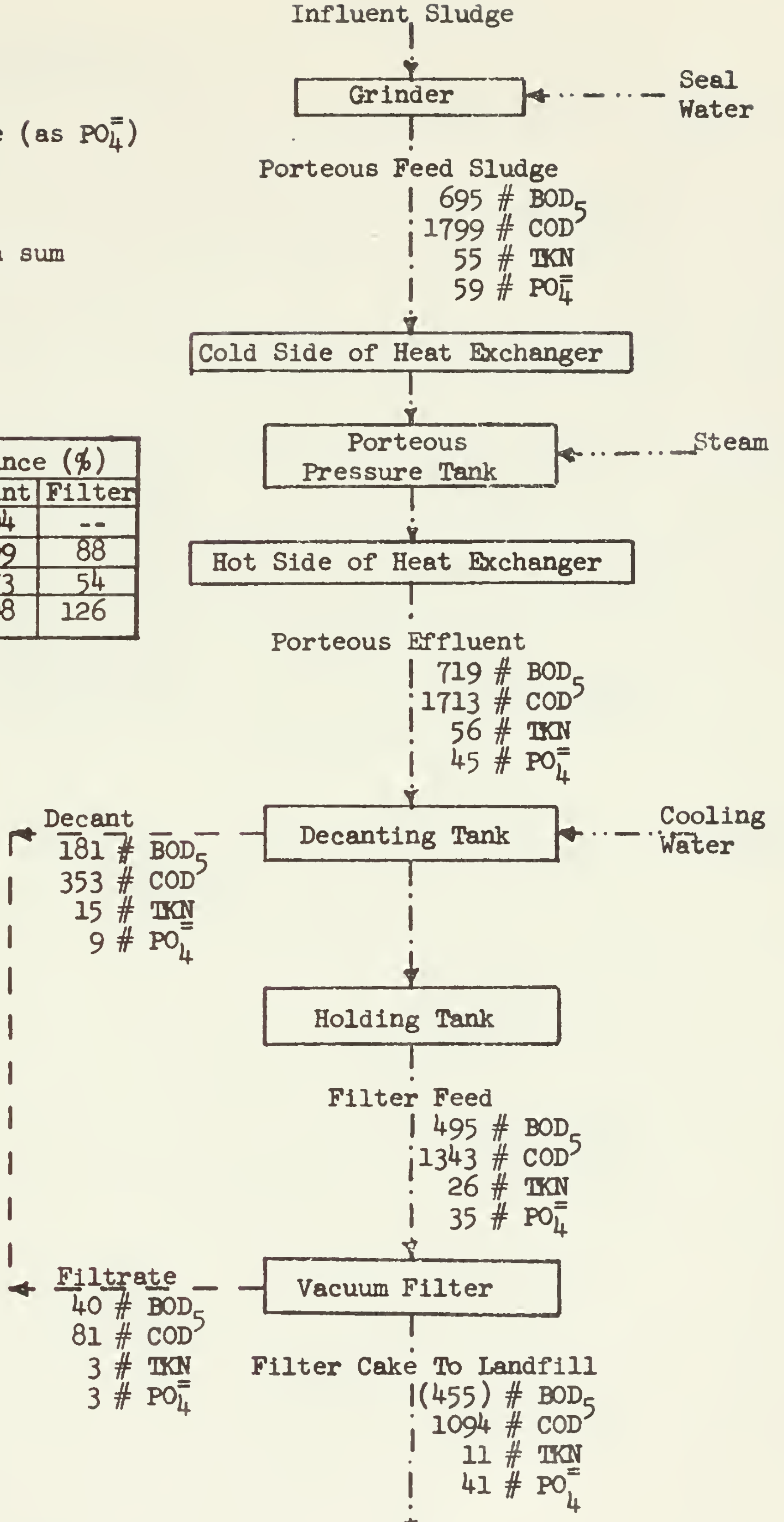
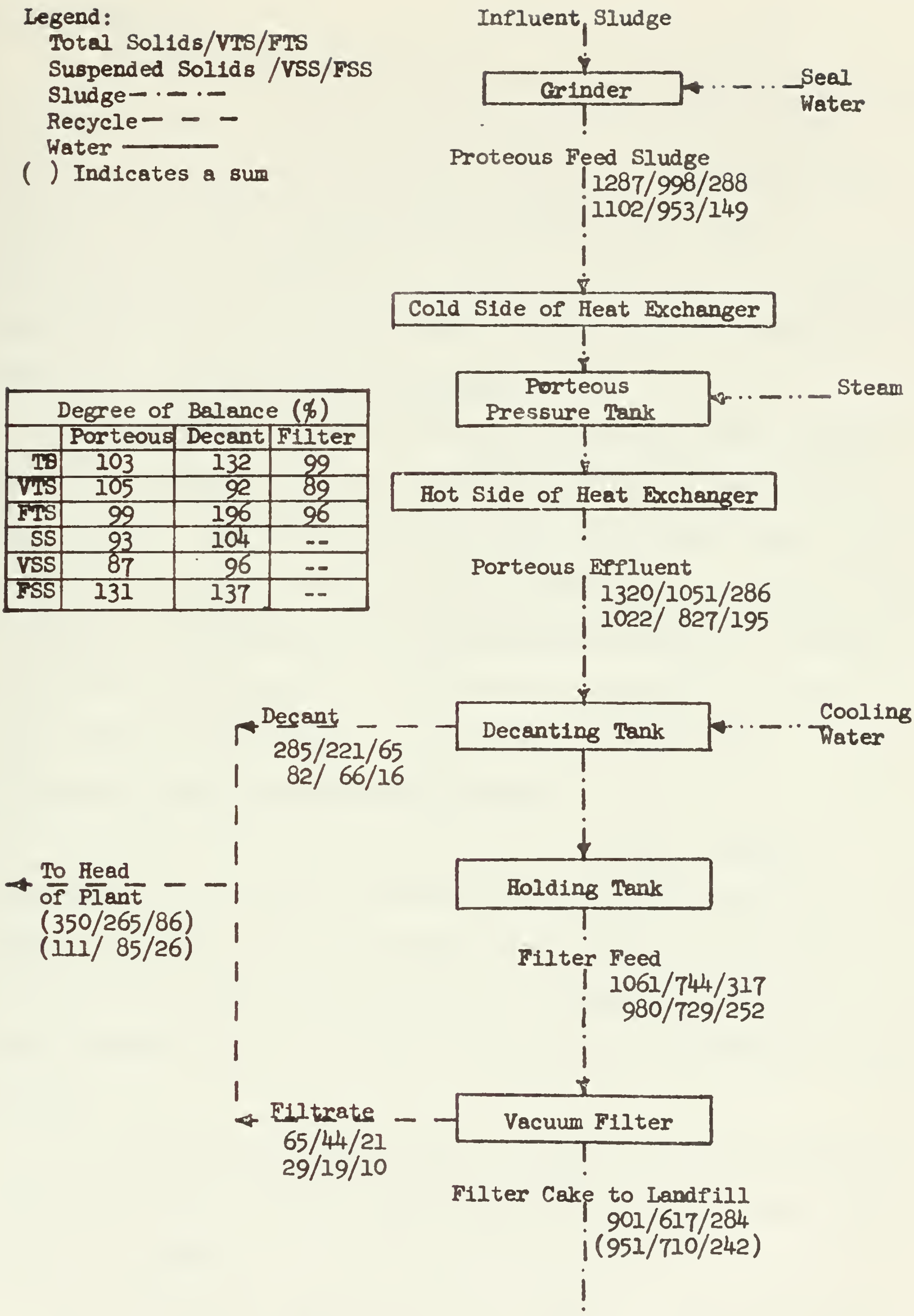


Figure 25. Material Balance for Porteous Process on Oct. 28, 1971
All values expressed in pounds per 1 MG treatment plant influent flow.



Degree of Balance (%)			
	Porteous	Decant	Filter
TS	103	132	99
VTS	105	92	89
FTS	99	196	96
SS	93	104	--
VSS	87	96	--
FSS	131	137	--

Figure 26. Solids Balance for Porteous Process on Oct. 28. 1971
All values expressed in pounds per 1 MG treatment plant influent flow.

Costs Analysis

Information available from the Colorado Springs plant showed operational costs to be very low at 5 cents/1000 gallons treated. However, costs per pound of pollutant removed was comparable to the other plants studied indicating generally that fewer pounds of pollutants were removed/MG at this plant. Capital construction costs and operational costs per treatment plant unit were not available.

Discussion of Results--Testing Comments

1. The parameter concentrations of the primary sludge used for material balances in the main treatment plant were the same as the feed sludge to the Porteous process. The Porteous feed sludge differs from primary sludge because an unknown amount of holding tank sludge has been mixed with the primary sludge, and then this mixture is diluted by seal water. A correction has been made for the seal water addition for the material balances in the main plant.

Discussion of Results--Operational Comments

1. The Parshall flume at the head of the plant, submerged during peak flows, presents problems in determining recycle flows. There is no meter on the recycle flow stream, so this flow is calculated by taking the difference between the influent and effluent meter readings. The recycle flow is thought to average between 6 and 9 MGD.

2. The volume of sludge removed in gallons is almost doubled by the volume of water added in the Porteous process and returned to the head of the plant.

3. The Porteous process literally cooks the sludge under heat and pressure conditions. The cooking process denatures the sludge

changing much of the wastes in the sludge.from solid to dissolved form. When cooling water is added to the treated sludge to improve settling characteristics, a transport media is provided to transport the wastes as decant back to the treatment plant.

Discussion of Results--Concluding Comments

1. Material balances on the primary clarifier varied between 84% to 110% of the material accounted for, but were mostly below 100%. The balances would have been closer to 100% if the recycle volume had not been as great reducing the total volume of flow, hence the total pounds mass into the primary settlers. The primary settlers removed about 2/3 of the COD and suspended solids removed by the plant, and the trickling filters and secondary clarifiers removed about 2/3 of the BOD_5 removed by the plant. See Figure 23. All TKN removed was done by secondary treatment.

2. The only recycle in this plant is the recycling of a large volume of secondary sludge. How this scheme affects overall removal efficiency as compared to another scheme is unknown. It is questioned if recycling the major portion of trickling filter effluent directly back onto the filter and returning only a much smaller volume to the primaries wouldn't be a better scheme. The use of a mass balance would prove the more efficient scheme here.

3. What is the net affect of the Porteous process? From Figure 22, it can be seen that 30-40% of all wastes removed via primary sludges are returned to the main plant as filtrate or decant. Only suspended solids are effectively removed in this process. 80% of the TKN is returned. Combining the other three trickling filter plants studied with Colorado Springs, about 40% of

the BOD_5, COD, and suspended solids entering the primary tanks was removed as sludge. If 30% to 40% of the wastes removed as primary sludge is recycled by the Porteous process, then this would increase the total load on the plant by 12% to 16%! This is actually making more work for the plant.

Simple vacuum filtration of primary sludges as at Boulder returns 5% or less of the wastes removed by primary sludge, increasing the total load on a plant due to this type of sludge removal process by 2% or less. Decant from digested sludge at the Broomfield plant could return up to 10% of the wastes removed by primary sludge, increasing the total load on the plant by 4% or so.

The net effect of the Porteous process is to increase the load on a plant by three to eight times the amoung other sludge removal processes would. It should also be remembered that this is a trickling filter plant with a minimal amount of sludge produced by secondary treatment. It would be interesting to see what the affect would be if the Porteous process was to treat a large mass of sludge as produced by an activated sludge process.

Comparative economics between vacuum filtration, anaerobic sludge digestion and the Porteous process were not investigated. In determining which sludge treatment process is a best alternative, a comprehensive economic analysis should be included.

ASPEN METRO SEWAGE TREATMENT PLANT

ASPEN, COLORADO

Description of Plant

The Aspen Metro Sewage Treatment Plant is an extended aeration activiated sludge plant located alongside the Roaring Fork River northeast of the town of Aspen. The plant was designed to handle varying seasonal flows due to the resort nature of the town. Flow during the time of sampling was about .95 MGD. Design flow and retention time is .72 MGD and 24 hours respectively. The plant consists of conventional pretreatment before the raw sewage is mixed with recycled activated sludge. The mixed liquor flows to two mechanically mixed aeration tanks in parallel for treatment. A single secondary clarifier removes recycled activated sludge, and the clarifier effluent enters a polishing pond. The first half of the polishing pond is aerated. Pond retention time is 5 to 7 days. Plant effluent is released directly to the Roaring Fork River, a quality river.

All secondary sludge is recycled to the head of the aeration tanks except for a small amount which is wasted periodically. The waste activiated sludge is hauled by tank truck to sanitary landfill. The plant began operation in 1969 with a planned expansion in 1972. A detailed flow diagram, with flow conditions for the two sampling periods is given in Figure 27. Operating variables are defined in Appendix II.

Description of Sampling

Because of Aspen's geographical location from the University of Colorado, and since both the Aspen Metro and the Snowmass-at-Aspen

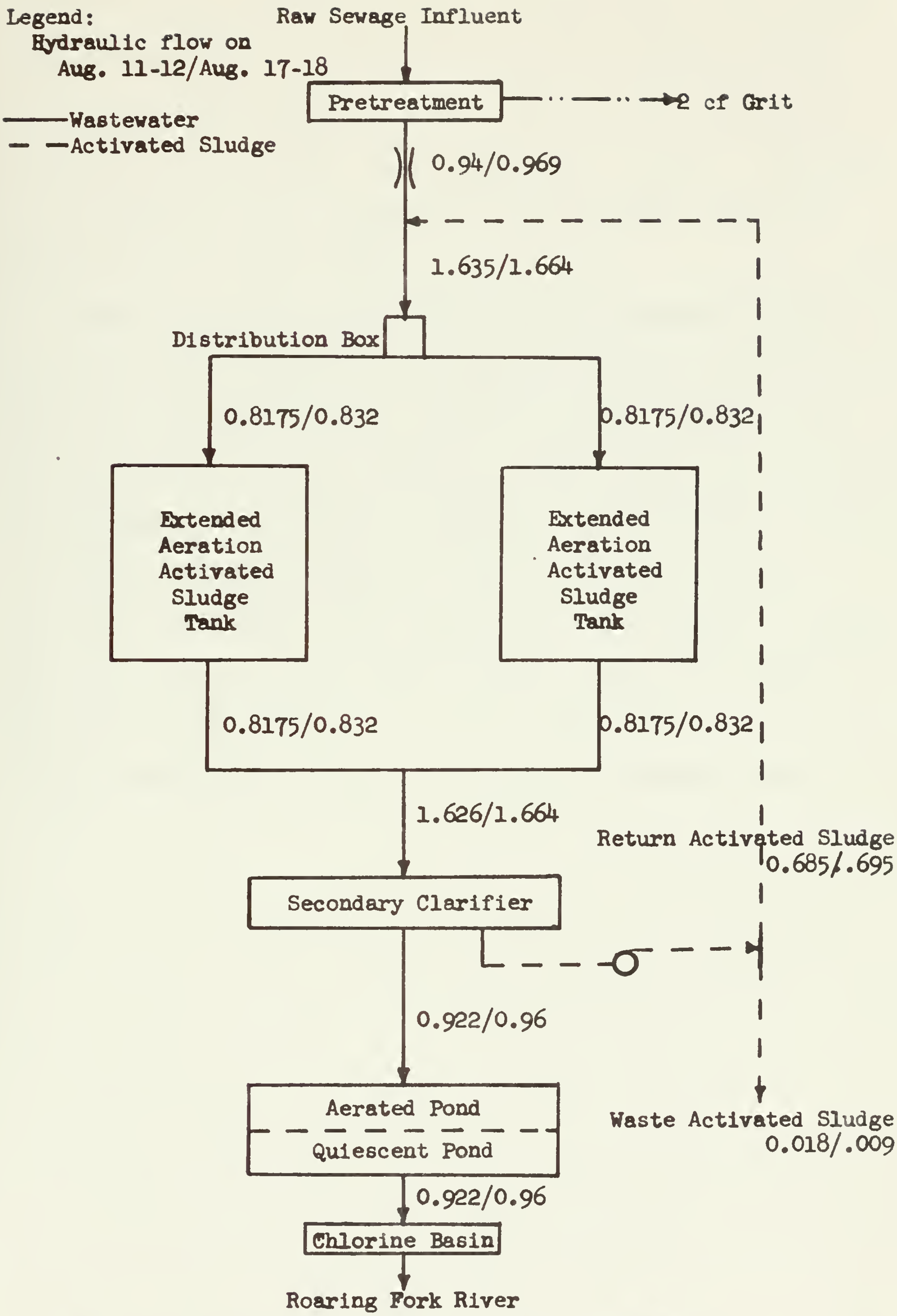


Figure 27. Hrdraulic Flow Diagram for Aspen Metro
All ow values are in MGD.

treatment plants were to be studied, it was decided to take samples from both plants over the same 24 hour period. Logistic problems limited the sample taking to every two hours at both plants, as compared to every one hour at the other plants studied. All samples at the Aspen plant were proportioned to the influent, except the return activated sludge sample.

Shortly before the first sampling period, a large volume of septic tank waste, unknown to the operator, was sent to the plant. The effect of the waste caused a drop in dissolved oxygen of the mixed liquor and a change in settling characteristics of the activated sludge. There were times during the sampling period when the secondary clarifier was bulking. The effect of the bulking is discussed later. There were no anomalies in plant operation during the second testing period on August 17-18. Samples were taken at the start, halfway, and the end of the aeration tanks in an attempt to trace the removal of a pollutant through the aeration tanks.

TABLE V

Parameter --- Testing Period	Plant Inf. mg/L	Extended Aeration Tanks: Tank Inf. mg/L	Tank Eff. mg/L	% of Tank Inf. Removed	Secondary Clarifier: Sec. Inf. mg/L	Sec. Eff. mg/L	% of Sec. Inf. Removed	% of Plant Inf. Removed	Polishing Pond: Pond Inf. mg/L	Pond Eff. mg/L	% of Pond Inf. Removed	% of Plant Inf. Removed
Plant/Unit Removal Efficiencies for Aspen Metro Sewage Treatment Plant												
BOD-I	250	2151	1481	31	1609	50	97	80	50	10	80	96
BOD-II	133	2161	2033	6	2033	40	98	70	40	16	60	88
COD-I	526	5565	5730	-3	6125	95	98.5	82	95	46.7	51	91
COD-II	242	9055	8673	4	8673	61	99.3	75	61	31	49	87
TKN-I	26.2	288	270	6	318	13.5	96	48.5	13.5	15	-11	43
TKN-II	19.1	275	262	5	262	12	95.4	37	12	11.6	3	39
PO_4-I	27	203	230	-13	250	14	94.6	50	13.6	23.2	-71	14
PO_4-II	21.3	259	245	5	245	17	93	22	16.6	15	10	30
TS-I	706	6162	5922	4	6658	530	92	25	530	456	14	35.4
TS-II	666	5135	4825	6	4825	425	91	36	425	384	10	42
VTS-I	442	4089	3902	4.6	4430	246	94.5	44	246	187	24	58
VTS-II	326	3574	2282	36	2282	144	93.7	56	144	118	18	64
FTS-I	264	2073	2020	2.6	2228	283	87	-7	283	270	4.6	-2.2
FTS-II	340	1561	1543	1.2	1543	281	82	17.4	281	266	5.3	22
SS-I	351	5810	5584	4	6105	58	99	83.5	58	8	86	98
SS-II	135	4227	4473	-5.8	4473	51	99	62	51	3.5	93	97.4
VSS-I	309	4032	3870	4	4210	39	99	87.4	39	5	87	98.4
VSS-II	112	3062	3303	-8	3303	37	99	67	37	2.5	93	98
FSS-I	42	1778	1714	3.6	1895	18	99	57	18	3	83	93
FSS-II	23	1165	1170	- .4	1170	13	99	43.5	13	1	92	96

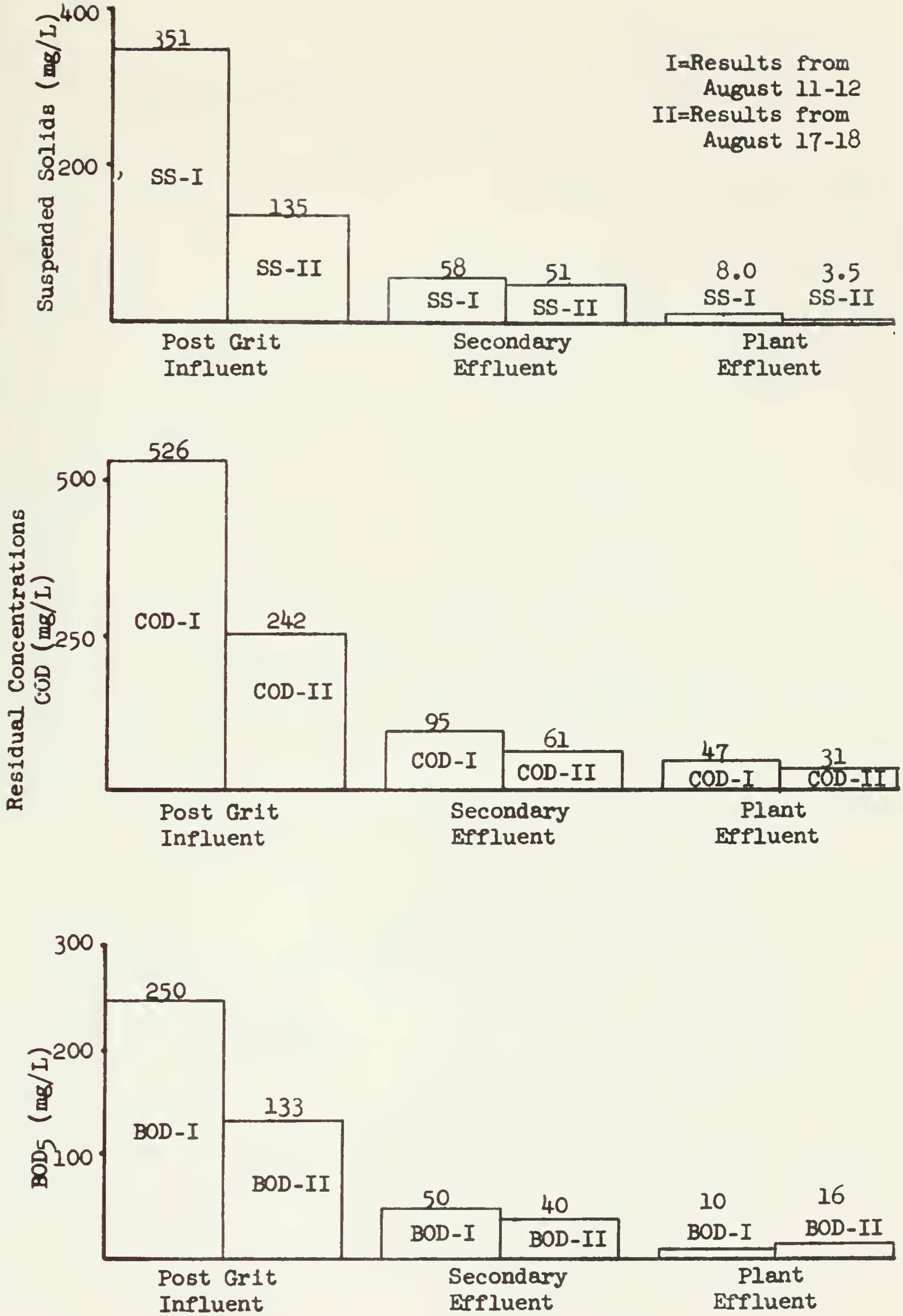


Figure 28. Residual Concentrations for Aspen Metro

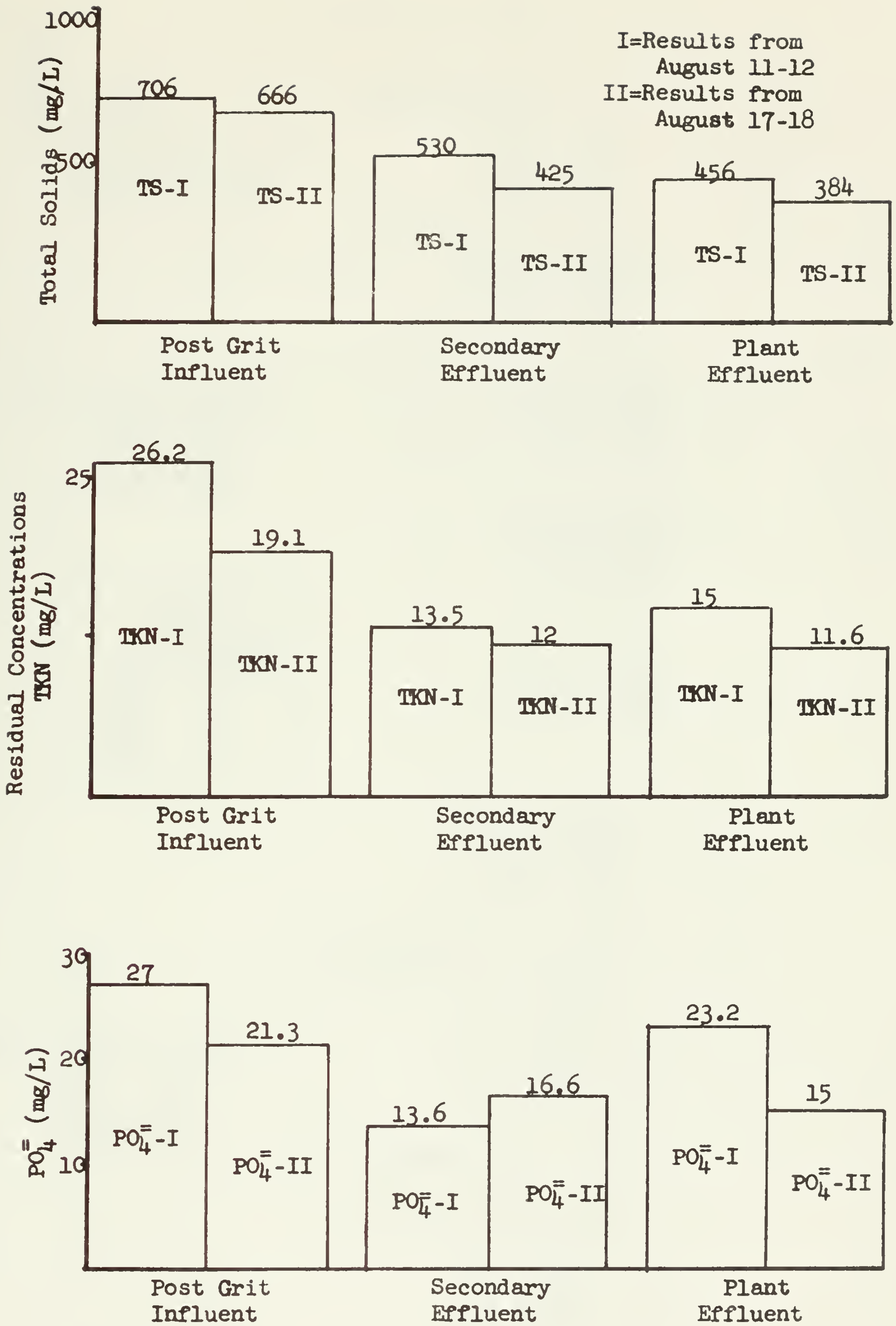
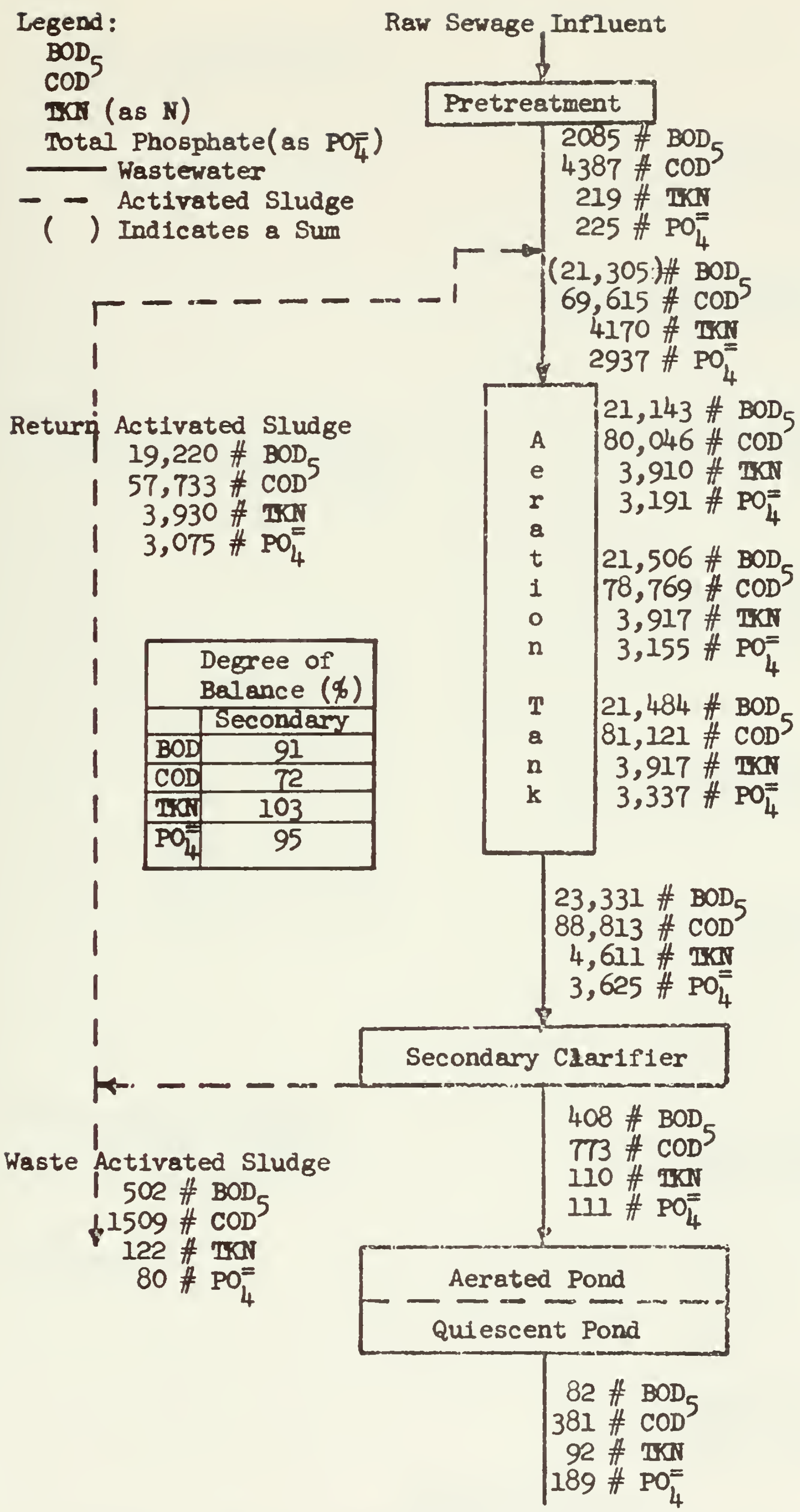
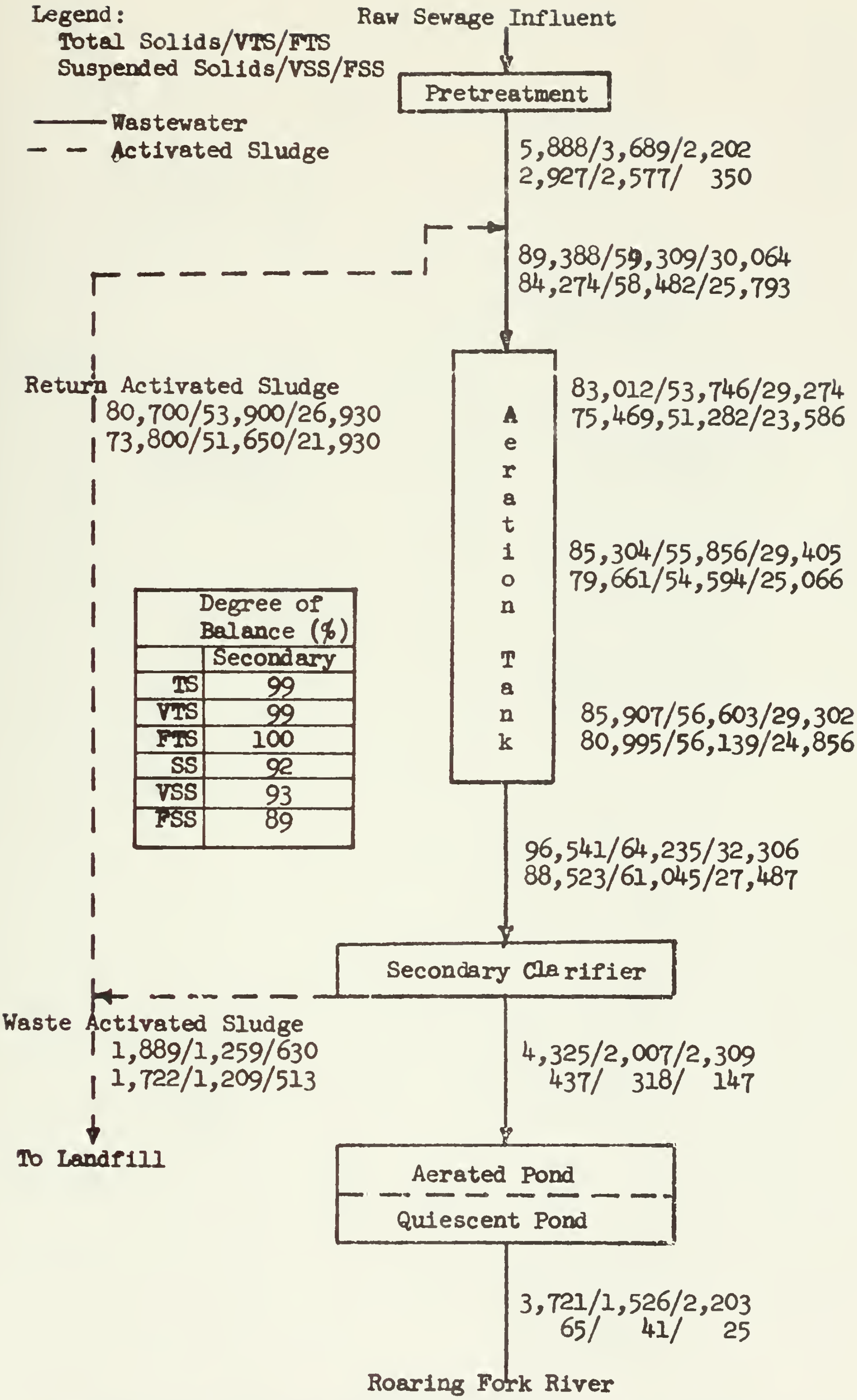


Figure 28. (cont.) Residual Concentrations for Aspen Metro



Degree of Balance (%)	Secondary
BOD	91
COD	72
TKN	103
$PO_4^=$	95

Figure 29. Material Balances for Aspen Metro on Aug. 11-12, 1971
All values expressed in pounds per one MG influent flow.



	Degree of Balance (%)
	Secondary
TS	99
VTS	99
FTS	100
SS	92
VSS	93
FSS	89

Figure 30. Solids Balance for Aspen Metro on Aug. 11-12, 1971
All values expressed in pounds per one MG influent flow.

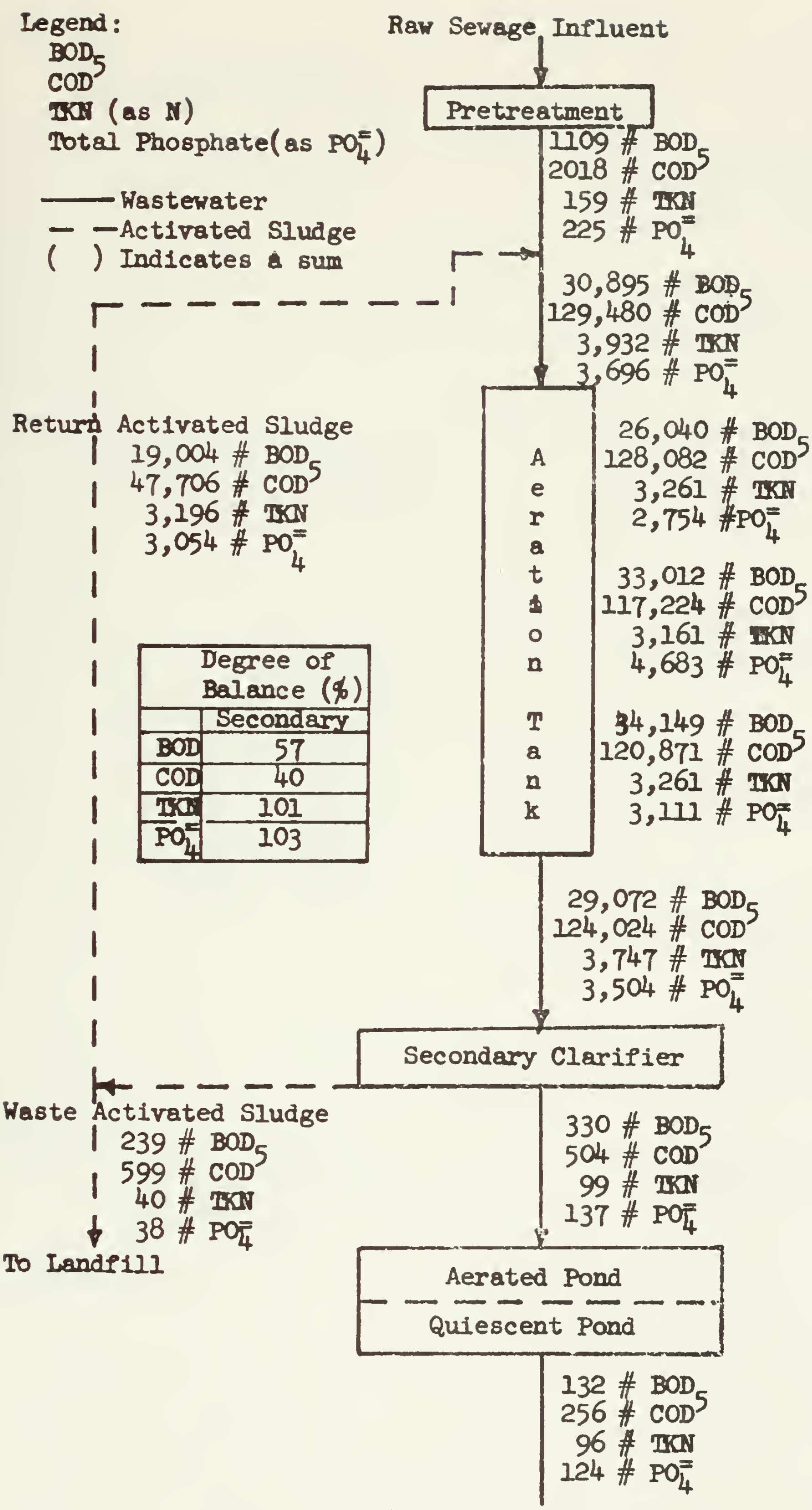
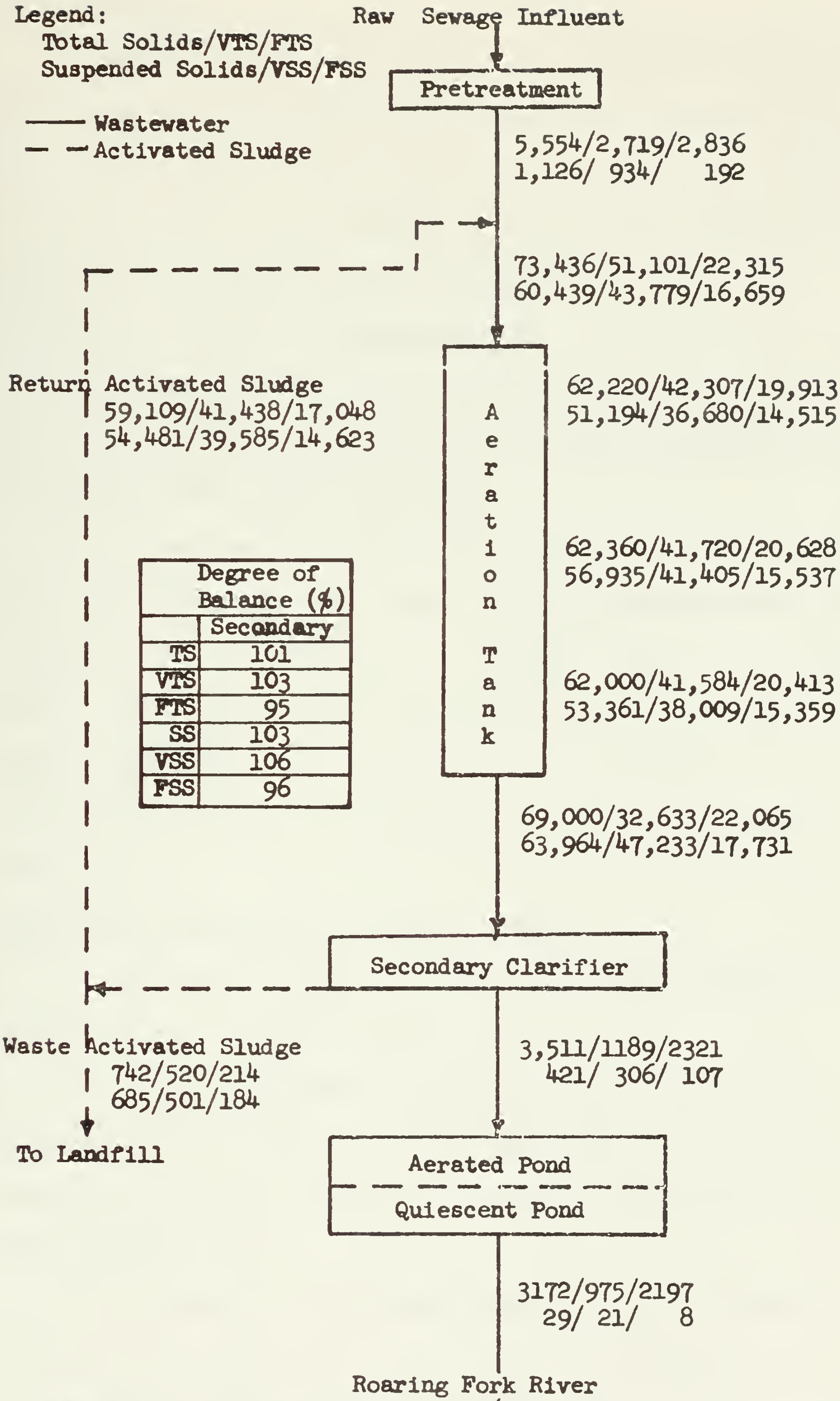


Figure 31. Material Balances for Aspen Metro on Aug. 17-18, 1971
All values expressed in pounds per one MG influent flow.



	Degree of Balance (%)
	Secondary
TS	101
VTS	103
FTS	95
SS	103
VSS	106
FSS	96

Figure 32 Solids Balance for Aspen Metro on Aug. 17-18, 1971
All values expressed in pounds per one MG influent flow.

Costs Analysis

Operational costs at Aspen were 10.8 cents/1000 gallons treated, and total cost for treatment was 24 cents/1000 gallons. These costs were higher than most other plants. However, costs per pound of pollutant removed were comparable to other plants because of the high removal efficiencies per MG treated.

Discussion of Results--Testing Comments

1. The septic tank wastes which reduced the D.O. in the aeration tanks and caused bulking in the secondary clarifier did not materially affect removal capacities.

2. A test result inconsistency occurred when the concentration of the "secondary influent" sample point was always greater than the average of the two "aeration tank effluents" sample. See Appendix VIII for data. The two sampling points represent virtually the same mixed liquor. Much thought was given to this inconsistency, but no rational reason could be found other than poor sampling technique.

Discussion of Results--Operational Comments

1. Little can be discussed about the plant's operation due to the fact that it was operated quite well.

2. The lower removal efficiencies, Table V, for the second study period when the plant had no upsets were due to the weak influent raw sewage. Absolute concentrations for the second period were actually lower.

3. The plant is being loaded, hydraulically overloaded, to such an extent that in order to prevent a rapid build-up of solids in the aeration tank, recycled activated sludge had to be wasted at

the rate of 3000 gallons per day. Partial step aeration, two separate inputs to each tank, was being used at this time also.

Discussion of Results--Concluding Comments

1. BOD_5, COD, and suspended solids removal correlated very closely through each stage of plant operation. See Figure This observation is similar to comments made about trickling filter plants.

2. Phosphate and TKN removal was of the same magnitude as total solids and followed the same removal pattern. There was little or no change in the TKN concentration in the polishing pond indicating that no nitrification took place.

3. The discharge of treated sewage at Aspen Metro is regulated by a discharge permit granted under the Refuse Act of 1898 by the Army Corps of Engineers. The receiving Roaring Fork River is an A-B1 (20) stream. As a consequence, the Aspen Metro plant had to be designed to produce a water suitable for discharge under these conditions. The key to Aspen Metro's ability to do this is the polishing pond. Looking at secondary clarifier effluent during the first sampling period, BOD_5, COD, and suspended solids reached removals of 80%, 82%, and 83.5% respectively. For the second study period, no removal was over 75%. However, the plant effluent before chlorination had removals from 87% to 98% for these parameters for both sampling periods. The polishing pond is the plant's shock absorber. Even though the pond influent may vary a great deal, the effluent waste concentrations remained constant or changed very slowly. Without the polishing pond, this plant couldn't consistently meet the high standards, or it would have to be uneconomically

over-designed. In defense of the plant though, it should not be overlooked that it is operating at 30% to 35% over its designed capacity.

4. An important evaluation on the use of material balances on activated sludge plants should be made at this time. It was hoped that the removal of a waste parameter could be traced through the extended aeration tank. This proved to be a hard or impossible task for four reasons.

a. The activated sludge suspended solids (biomass) can act as a reservoir accumulating or relinquishing masses of waste parameters as the mass of the activated sludge increases or decreases. Accumulation occurs when the biomass is in logarithmic or exponential growth. Relinquishment occurs when endogenous respiration is predominant.

b. Analytical tests have to be run over a period of time to get 1) values that are statistically significant, and 2) values that are not affected by accumulation or depletion of the biomass.

c. Assume that the recycled activated sludge remains constant in strength and doesn't change so that what is measured is the change in the waste being treated. This waste is mixed in a ratio of 1 to 2/3 or 1 to 1 with recycled activated sludge. In most parameters for Aspen, and for the Snowmass plant to be discussed later, the R.A.S. was twenty times more concentrated than the influent raw sewage, so that the technician is essentially trying to trace the removal of 1 part in 21 parts.

d. Tests conducted on a mixed liquor are difficult in themselves due to large dilution, and obtaining representative sample aliquots.

5. The observations made above preclude the evaluation of the aeration tanks. Balances on the secondary clarifiers at Aspen showed errors from 40% to 103% for non-solids parameters. Solid balances were quite accurate varying only from 92% to 103% of the material accounted for. A computation of mass conversion from BOD_5 and COD to CO_2 and biomass was not undertaken because of lack of precision in solids, BOD_5, and COD test results.

SNOWMASS-AT-ASPEN SEWAGE TREATMENT PLANT

SNOWMASS-AT-ASPEN, COLORADO

Description of Plant

The Snowmass-at-Aspen Sewage Treatment Plant, located in the Snowmass Valley near Aspen, serves a developing resort area. This plant, like the Aspen Metro plant, receives highly varying seasonal flows. These flows are at their peak during the summer vacation period and during the winter skiing season. The plant is an extended aeration, activated sludge process that periodically wastes activated sludge to landfill. A partially aerated polishing pond helps to meet the high effluent standards required in the Aspen area. Plant effluent flows via Brush Creek to the Roaring Fork River. An aerated grit chamber removes the grit before the raw sewage enters the single aeration tank. Return activated sludge from the rectangular secondary clarifiers is recycled to the head of the aeration tank. A complete hydraulic flow diagram is given in Figure 33. The plant operating variables which occurred during the sampling periods are presented in Appendix II. Laboratory data for the Snowmass plant is contained in Appendix IX.

The plant is presently undergoing modification from its 0.32 MGD extended aeration process to a higher rate activated sludge process that will employ aerobic digestion of waste activated sludge to reduce the mass of sludge sent to landfill. Operation is to begin in the later part of 1971

Description of Sampling

As mentioned earlier, the Snowmass plant was sampled in conjunction with the Aspen Metro plant. Samples were proportioned

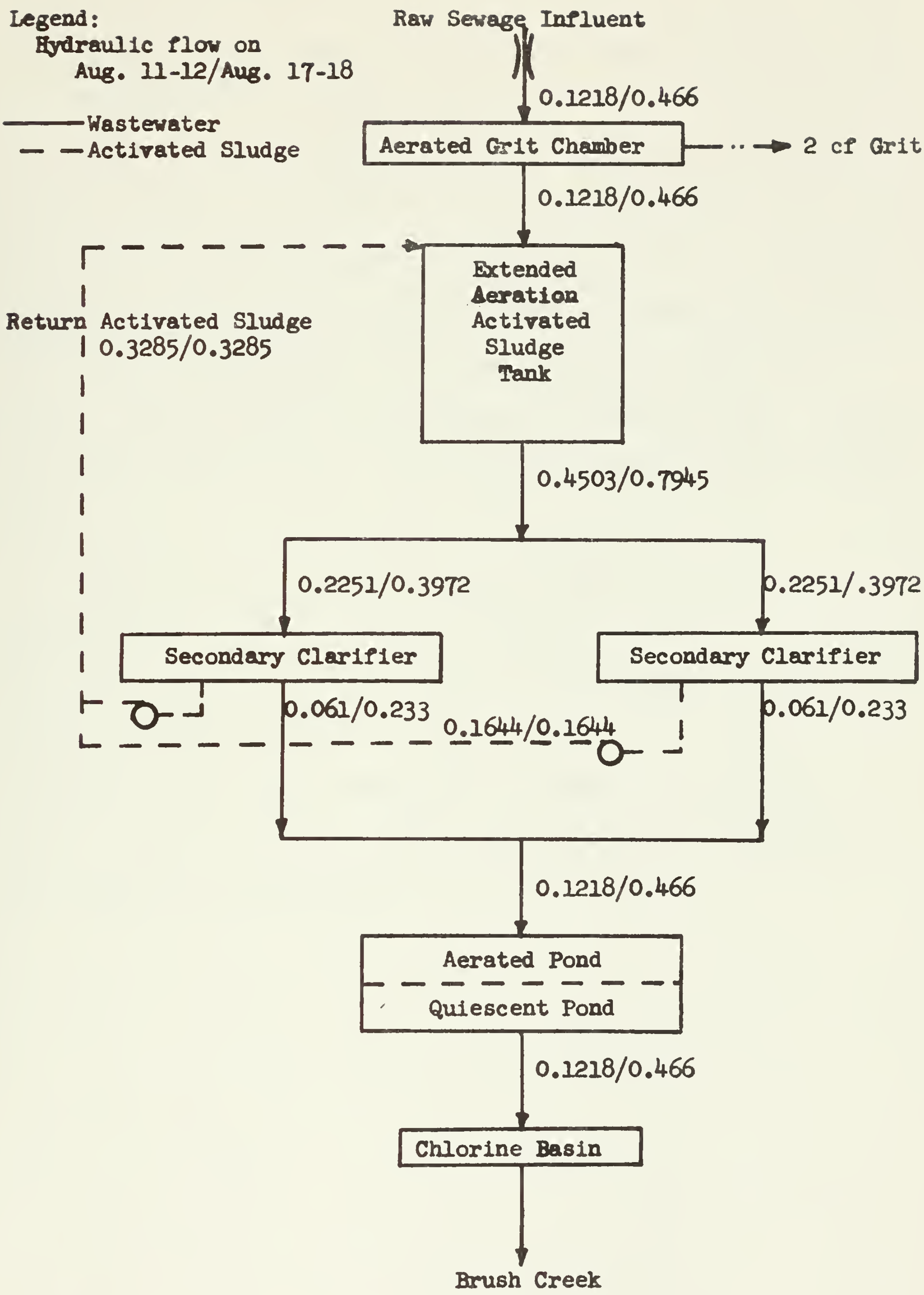


Figure 33. Hydraulic Flow Diagram for Snowmass-at-Aspen
All flow values are in MGD.

to influent flow meter readings. Return activated sludge is pumped at a constant rate, therefore this sample was not proportioned. The return sludge, drawn from two clarifiers, flows in a common line to be recycled. This arrangement prevented sampling of each secondary sludge separately. Likewise, the two secondary effluents were sent via a common line to the center of the aerated pond, so a combined secondary effluent sample could not be taken. Samples were taken at the start, one-third point, two-thirds point, and effluent of the aeration tank to trace removals through the aeration tank. The plant was sampled twice, first on August 11-12 and second on August 17-18, 1971.

For seven hours prior to the commencement of sampling of August 17-18, return sludge pumps were shut down because of construction. The first two samples, a period of three hours, of the secondary clarifier effluent contained higher concentration of suspended solids. The return activated sludge also had high percent solids. The affect this change in plant operation had on the system is discussed later.

TABLE VI

Plant/Unit Removal Efficiencies for Snowmass Sewage Treatment Plant												
Parameter --- Testing Period	Plant	Extended Aeration Tanks			Secondary Clarifier				Polishing Pond			
	Inf. mg/L	Tank Inf. mg/L	Tank Eff. mg/L	% of Tank Inf. Removed	Sec. Inf. mg/L	Sec. Eff. mg/L	% of Sec. Inf. Removed	% of Plant Inf. Removed	Pond Inf. mg/L	Pond Eff. mg/L	% of Pond Inf. Removed	% of Plant Inf. Removed
BOD-I	128	1833	4524	-146	4524	21	99.5	84	21	18	14	86
BOD-II	185	5300	5240	1	5240	95	98.2	49	95	30	68	84
COD-I	250	4980	4960	.5	4960	24	99.5	90.5	23.5	52	-121	79
COD-II	284	7272	7507	-3	7507	128	98.3	55	128	57	55	80
TKN-I	19.1	223	237	-6	237	2	99	88.5	2.2	3.2	-45	83
TKN-II	22.2	212	193	9	193	11	94.4	51	10.9	4	63	82
$PO_4^{\equiv}$-I	20.3	260	270	-4	270	14	95	31	14	8	43	60.5
$PO_4^{\equiv}$-II	18.7	213	220	-3	220	24	89	-27	23.7	7.4	69	16
TS-I	499	6169	6230	-1	6230	326	95	35	326	418	-28	54
TS-II	565	5215	5132	1.6	5132	467	91	17	467	258	45	32.5
VTS-I	271	3358	3367	- .2	3367	166	95	39	166	183	-10	66.5
VTS-II	304	2839	2786	2	2786	198	93	35	198	102	48.5	-3
FTS-I	228	2811	2862	-1.8	2862	157	94.5	31	157	234	-49	40
FTS-II	260	2375	2346	1.2	2346	269	88.5	-3.5	269	156	42	79
SS-I	182	5708	5861	-2.7	5861	211	99.7	88.5	21	38	-81	80
SS-II	208	4802	4583	4.6	4583	220	95	-6	220	42	81	80
VSS-I	121	3126	3159	-1	3159	15	99.6	88	15	22	-47	82
VSS-II	135	2735	2485	9.2	2485	117	95	13	117	28	76	79
FSS-I	60	2582	2702	-4.6	2702	6	99.8	90	6	16	-167	73
FSS-II	72	2068	2097	-1.4	2097	104	95	-44	104	14	86	81

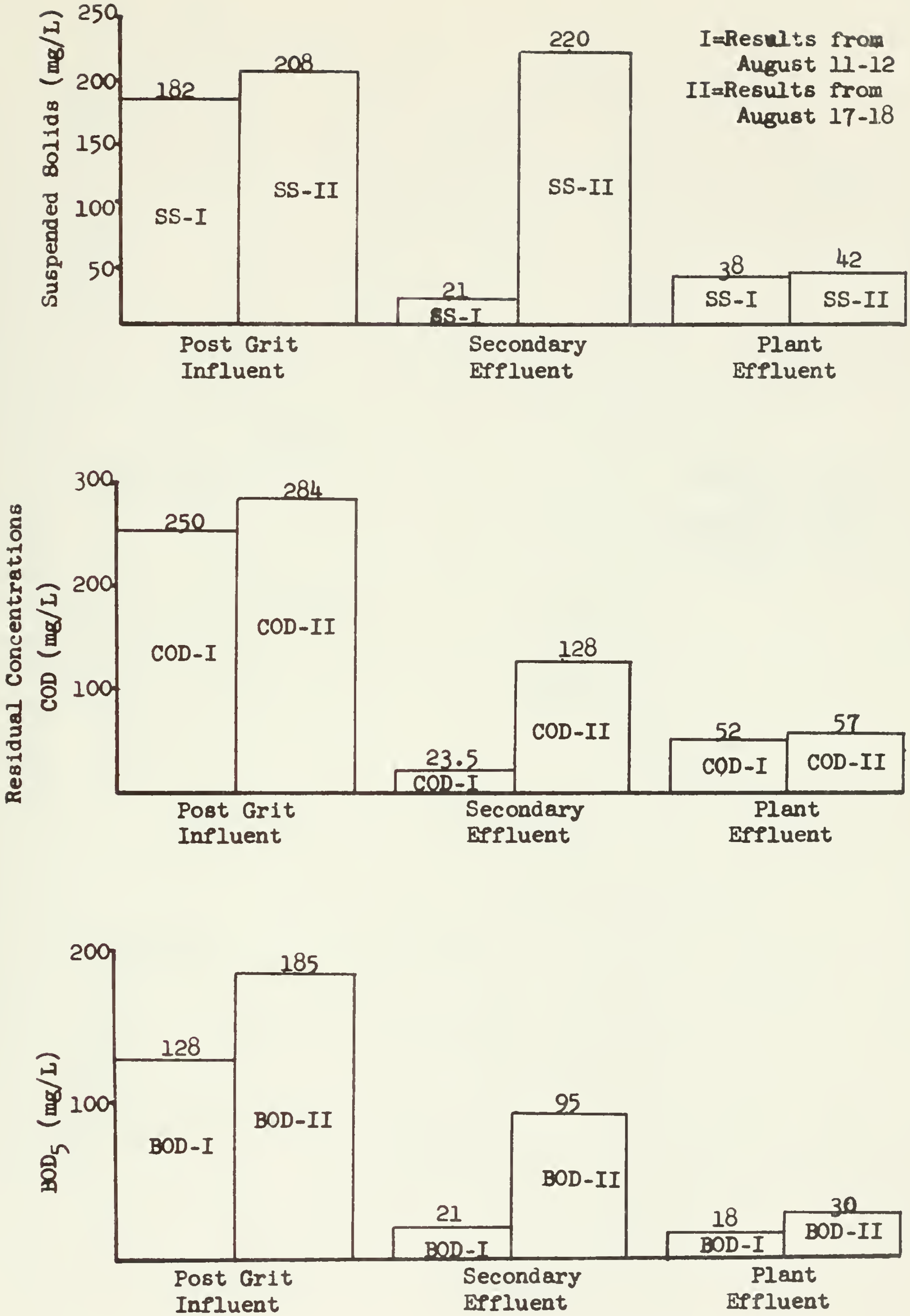


Figure 34. Residual Concentrations for Snowmass-at-Aspen

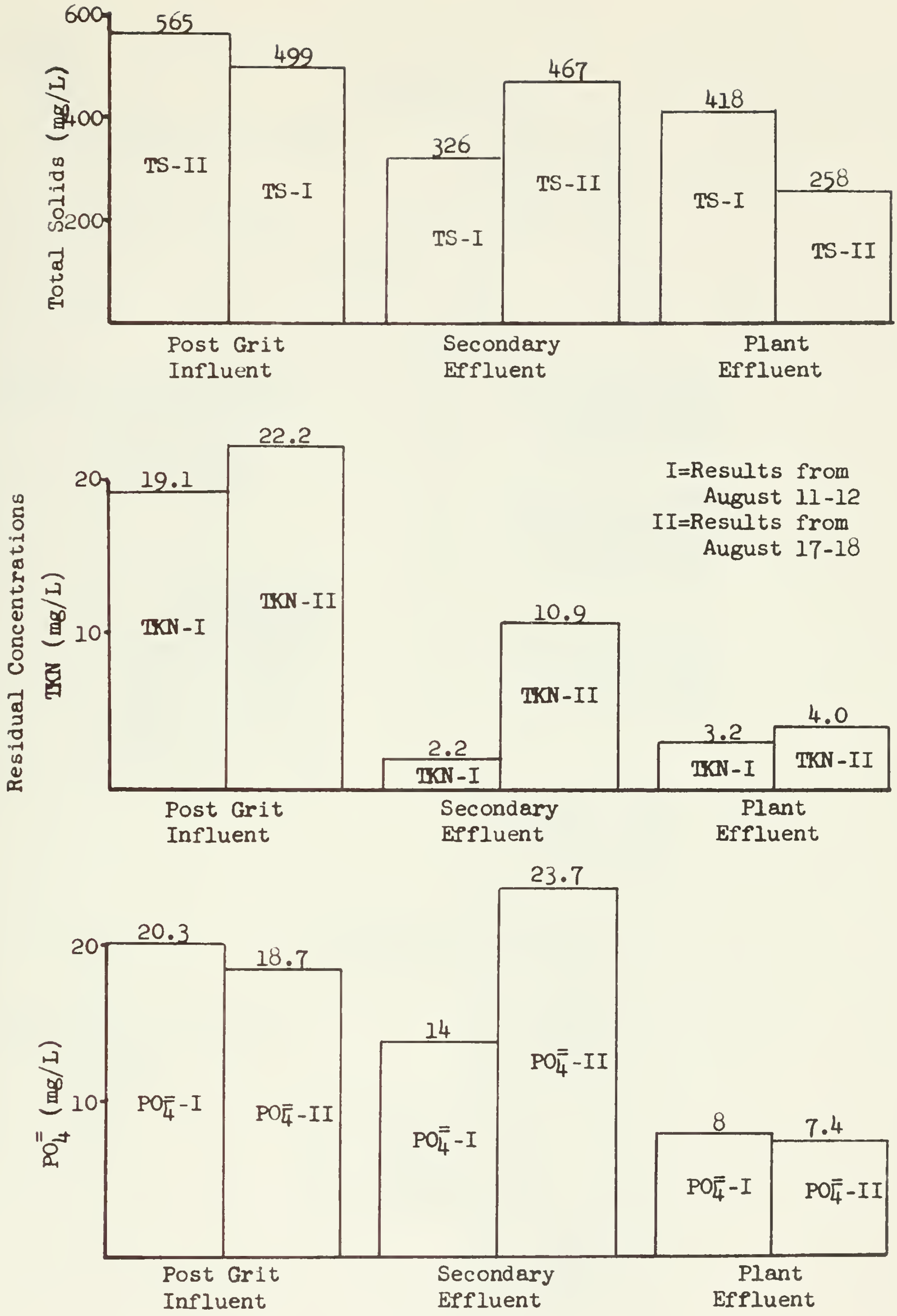
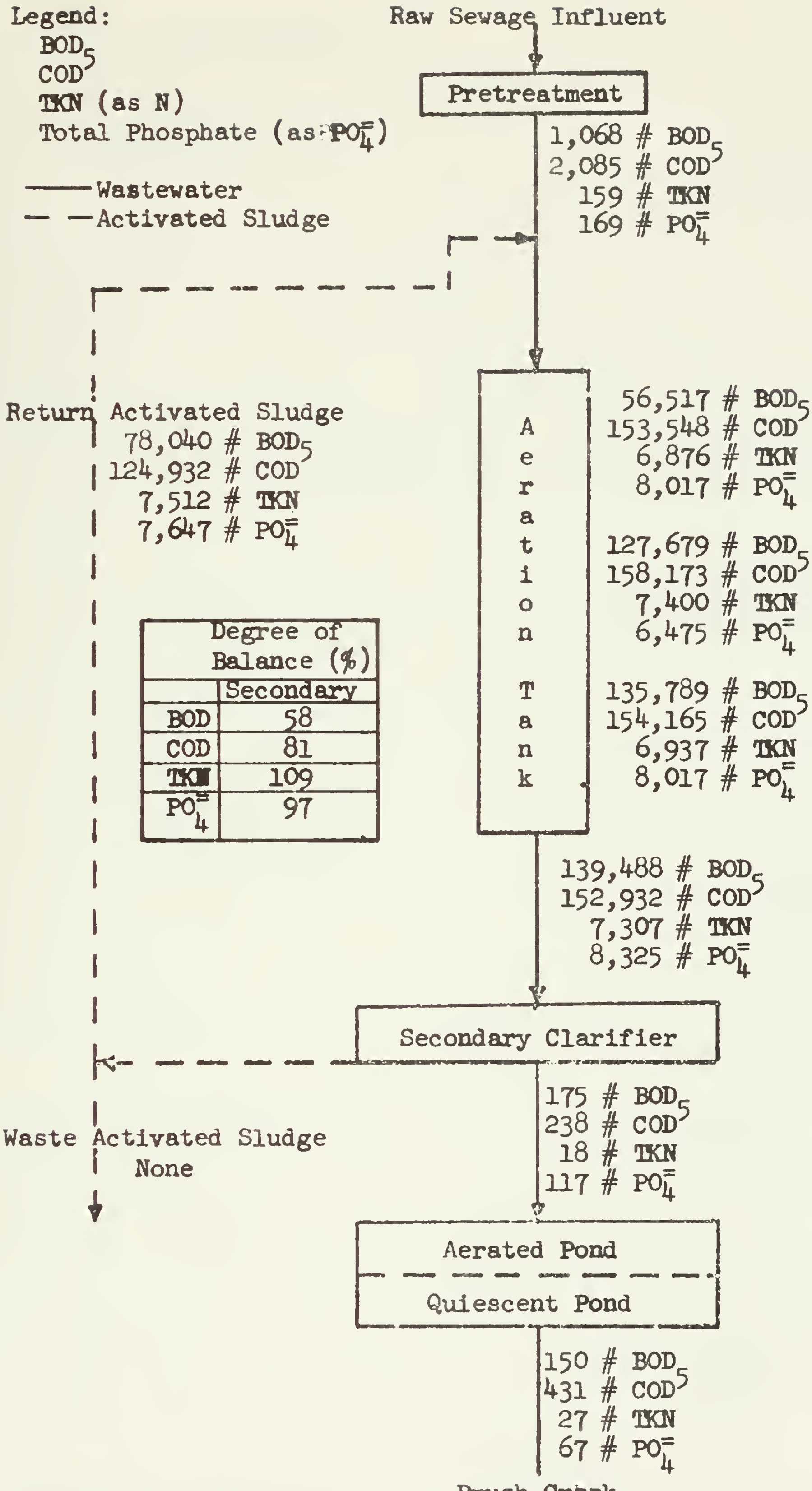
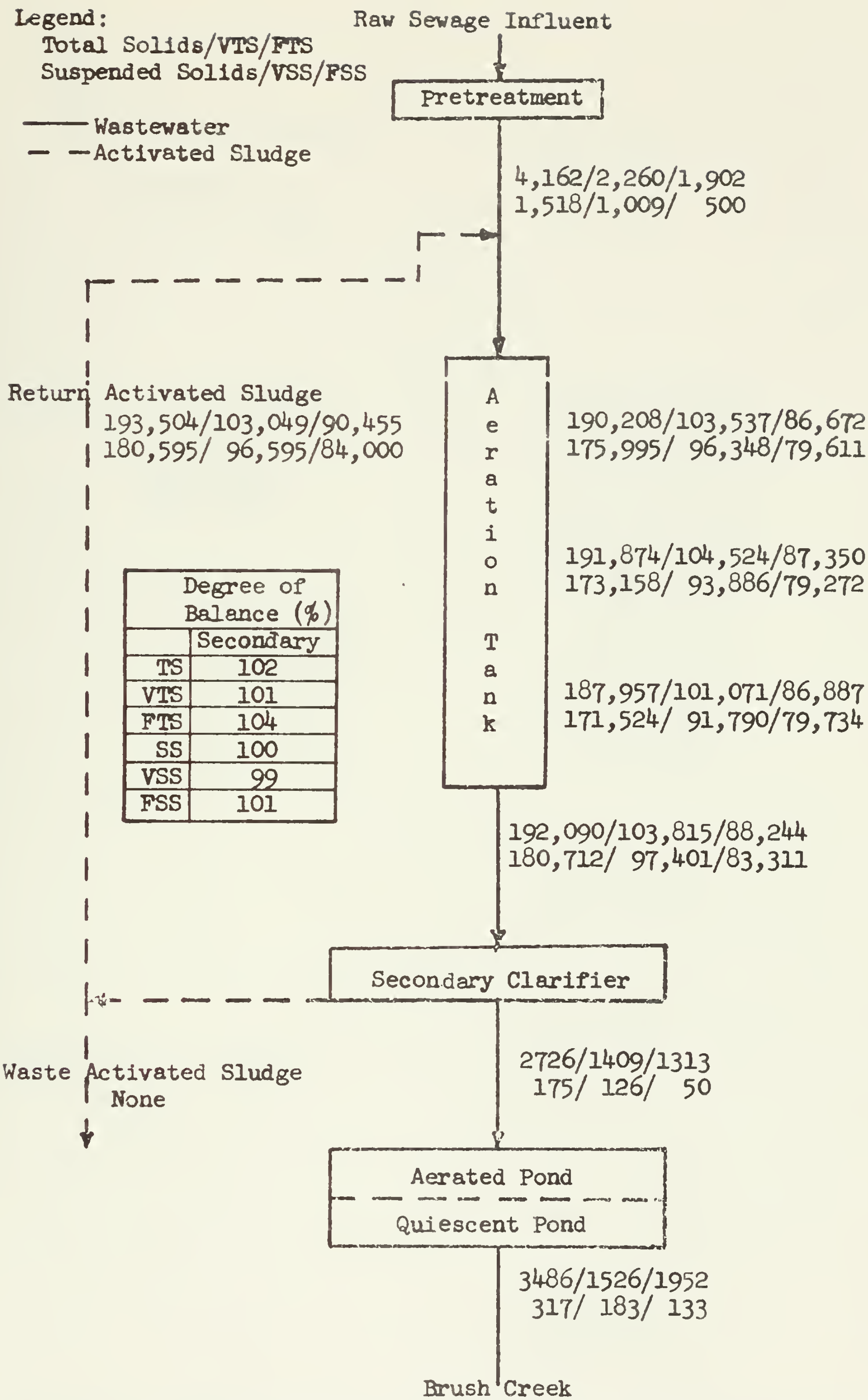


Figure 34. (cont.) Residual Concentrations for Snowmass-at-Aspen



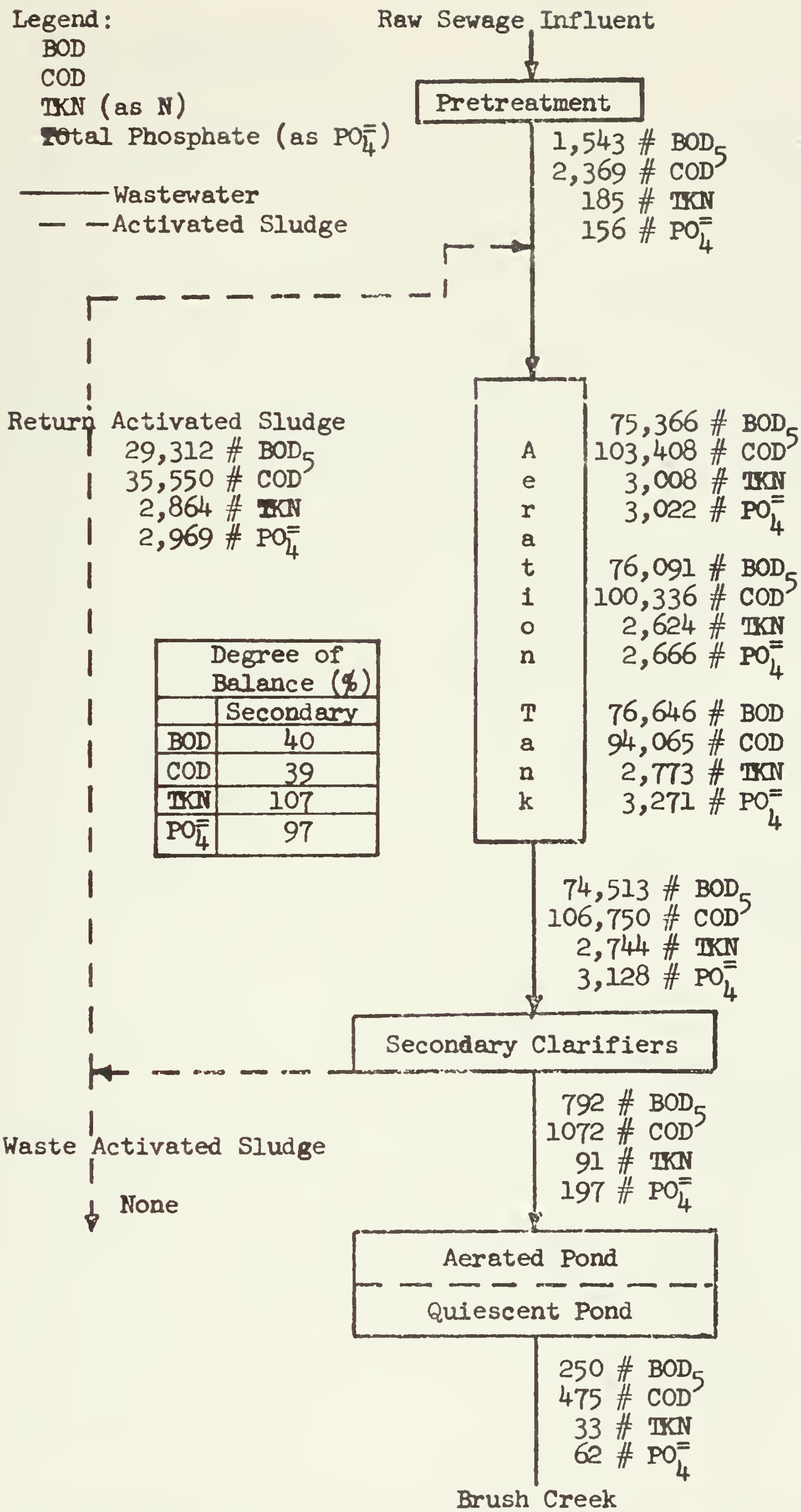
	Degree of Balance (%)
	Secondary
BOD	58
COD	81
TKN	109
$PO_4^{=}$	97

Figure 35. Material Balance for Snowmass-at-Aspen on Aug. 11-12,1971
All values expressed in pounds per one MG influent flow.



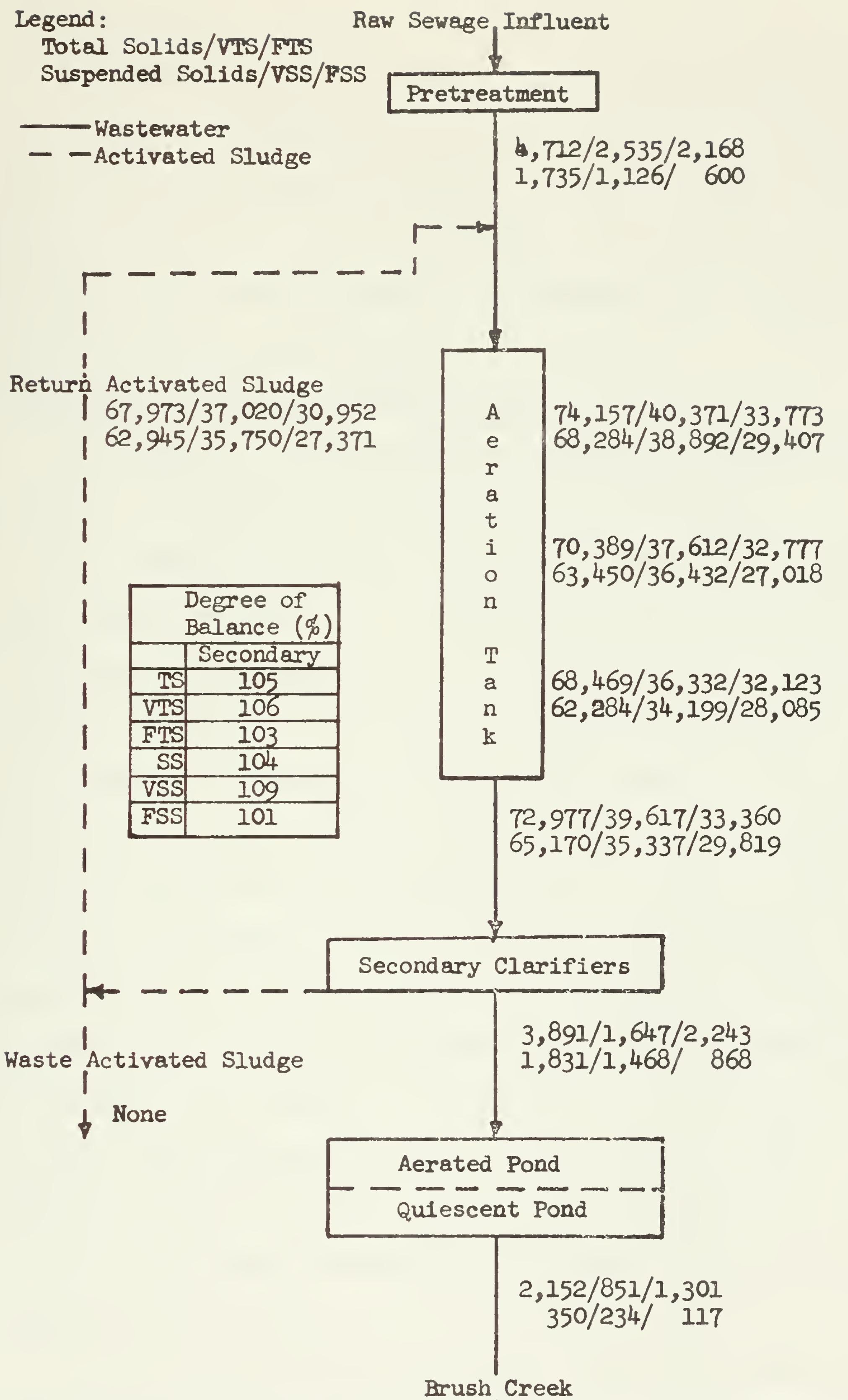
	Degree of Balance (%)
	Secondary
TS	102
VTS	101
FTS	104
SS	100
VSS	99
FSS	101

Figure 36. Solids Balance for Snowmass-at-Aspen on Aug. 11-12,1971
All values expressed in pounds per one MG influent flow.



	Degree of Balance (%)
	Secondary
BOD	40
COD	39
TKN	107
$PO_4^{=}$	97

Figure 37. Material Balance for Snowmass-at-Aspen on Aug. 17-18,1971
All values expressed in pounds per one MG influent flow.



Degree of Balance (%)	
	Secondary
TS	105
VTS	106
FTS	103
SS	104
VSS	109
FSS	101

Figure 38. Solids Balance for Snowmass-at-Aspen on Aug. 17-18, 1971
All values expressed in pounds per one MG influent flow.

Costs Analysis

Operational costs at the Snowmass plant was the highest of all the plants studied running 19.1 cents/1000 gallons. No capital cost information was available. Snowmass also had the highest capital construction cost per average MG treated. This may indicate great savings in economies of scale for capital costs when compared to a plant the size of Metro Denver.

Discussion of Results--Testing Comments

The Snowmass study has presented some problems that have subsequently raised questions about the results of the study.

1. A material balance was run on the secondary clarifiers for each sampling period to validate recycle activated sludge flows. It was known that the pumps could put out between 0.29 to 0.34 MGD. Parameter balance for the first sampling period, conducted as described in the beginning of this chapter, showed that the recycle flow should be approximately one MGD on four of the six parameters. The other two parameters gave higher results. Since this was physically impossible, and the test values seemed reasonable, it was conjectured that the influent flow was erroneous. Working backwards from the recycle flow computed for the second sampling period, which was .329 MGD, the influent flow was calculated to be .122 MGD instead of the .367 MGD recorded on the flow meter. Reasons to believe that the low flow actually occurred are:

a. The influent flow meter on the Parshall flume was to be readjusted periodically.

b. Plant influent TKN was 19.1 mg/L and the secondary clarifier effluent was 2.2 mg/L indicating a high (88.5%) TKN removal. This

change in concentration could have been accomplished by nitrification of the influent organic and ammonia nitrogen. No nitrate analysis was run on the secondary effluent sample. Nitrification can occur in activated sludge plants when there is a long detention period in the tanks caused by low flows.

c. BOD_5 and suspended solids concentration, 21 mg/L and 21 mg/l respectively, were extremely low for this type of treatment.

2. Testing anaomalies occurred at two locations in the plant.

a. The plant influent raw sewage, even though taken at two different locations (after communitor and in a hydraulic jump downstream of a flume) almost always had concentrations less than the "post grit influent" sample taken at the effluent weir of the aerated grit chamber.

b. The "aeration tank effluent" had higher concentrations than the sample taken at a point 2/3 through the aeration tank. As at Aspen, no rational explanation could be found.

Discussion of Results--Operational Comments

1. The shutting down of the recycle pumps for seven hours prior to commencement of the second testing period did not seem to affect the results of the material balance although this cannot be said to be representative of normal plant operation. Even with this change, good material balances were made.

Discussion of Results--Concluding Comments

1. Here again the polishing pond acts as a shock absorber taking both good and bad secondary effluent and converting it to a uniform pond effluent. See Figure 34.

2. The overall plant efficiency could have been increased for

the conditions described if secondary effluent bypassed the polishing pond for those periods when clarifier effluent was better than pond effluent. This is an example of where knowing what is happening in the plant by material balances can aid in the plant's overall efficiency.

3. BOD_5, COD, and suspended solids removal correlated very closely again. TKN removal correlated with these parameters this time. This high degree of nitrification, 82% overall, is probably due to a strain of nitrifying bacteria developed during low flow periods. Their activity and presence in the pond is probably fairly constant, but in the aeration tank their activity varies inversely with the flow. For the second sampling period, $PO_4^=$ removal followed total solids very closely. Figure 34. shows graphically the above comments.

4. Secondary clarifier balances for TKN, $PO_4^=$, total solids, and suspended solids varied between 97% and 107% of the material accounted for which was very good. BOD_5 and COD balances proved to be very poor indicating the difficulty of getting accurate test results for these parameters with sludges.

5. Because of the small plant size and extreme flows, this plant is highly susceptible to non-uniform operating conditions which make it hard to operate and evaluate.

METROPOLITAN DENVER SEWAGE DISPOSAL DISTRICT NO. 1

DENVER, COLORADO

Description of Plant

The Metro Denver Sewage Treatment Plant is a conventional rate activated sludge treatment system, operating under high rate conditions, with conventional primary and secondary clarification. Approximately 3/4 of the flow has received primary treatment at the Denver North Side plant. The other one fourth of the flow from the Clear Creek and Sand Creek outfall sewers receives pretreatment and primary settling before being mixed with the Denver North Side effluent. The combined primary treated wastewater, mixed with recycle activated sludge, passes through one of eight 3-pass aeration basins. The return activated sludge is the only recycle stream in the secondary treatment system.

Primary treatment at Metro Denver is designed for 30 MGD, and secondary treatment is designed for 117 MGD. A schematic flow diagram showing the hydraulic flow for the study period is given in Figure 39.

Sludge treatment, processing, and handling is very diverse at Metro Denver. There are three types of sludge handled: primary, aerobically digested waste activated, and anaerobically digested. Waste activated sludge undergoes aerobic digestion for about eight days in four converted aeration tanks. Digested sludge is concentrated by air floatation. Polymers are added to assist in the floatation process. The concentrated waste activated sludge is sent to a holding tank while the subnatant from the process is returned to the activiated sludge tanks. Primary sludge is sent directly to the

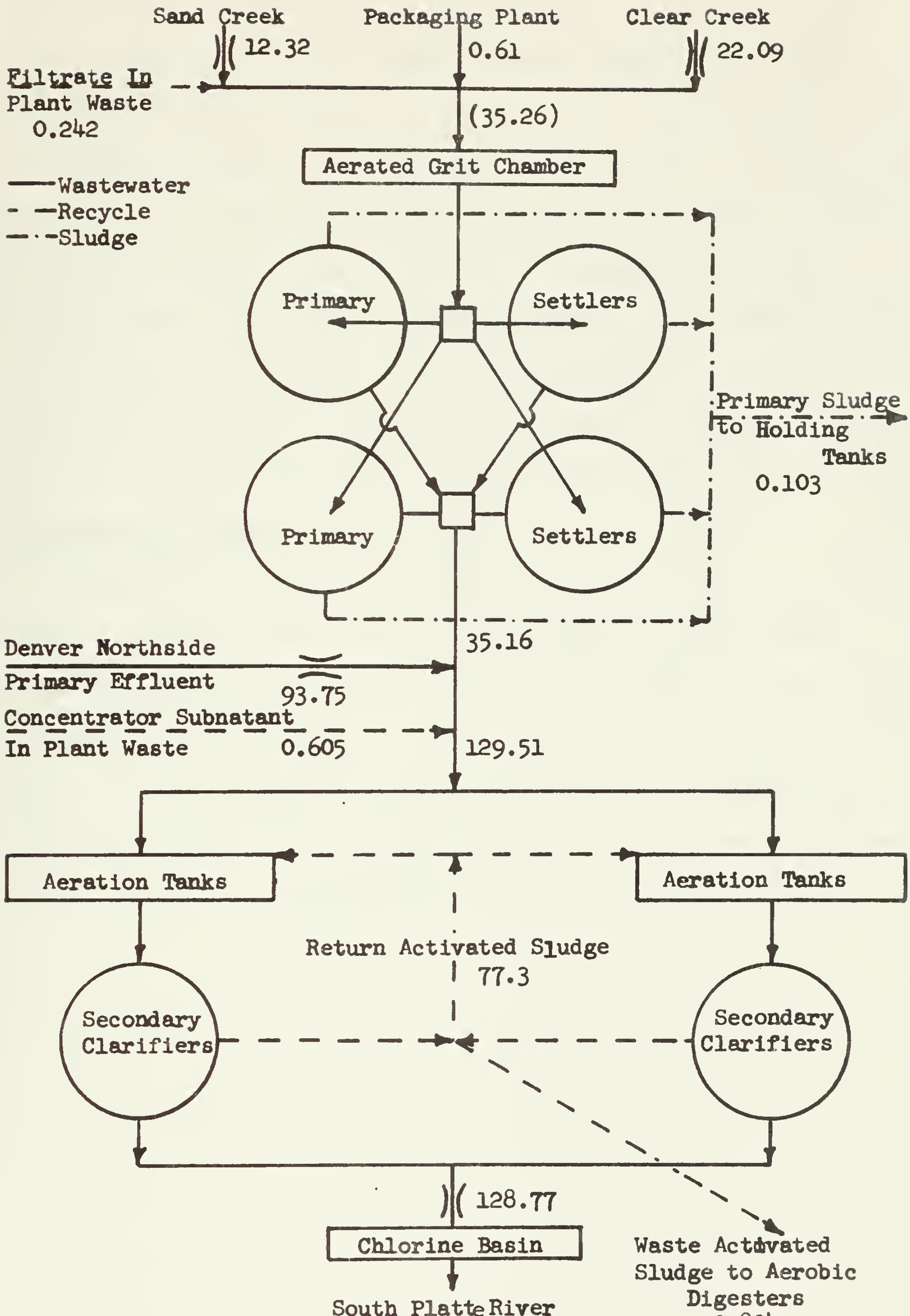


Figure 39. Hydraulic Flow Diagram for Metro Denver
All values expressed in MGD.

holding tanks. Anaerobically digested sludge is pumped twice weekly from the Denver North Side plant to holding tanks at Metro Denver. The three types of sludges are mixed in a smaller holding tank prior to vacuum filtration. The mixed sludges are dosed with lime (approximately 30% dry weight basis) and a ferric chloride solution (approximately 8% dry weight basis), and vacuum filtered on coil-spring vacuum filters. The filter cake is presently being hauled by truck to landfill. The filtrate from the filter process is sent back to the head of the plant. A schematic flow diagram showing all of the essential sludge handling processes is given in Figure 40.

Description of Sampling

The Metro Denver plant conducts its own daily evaluation of the plant's operation. This is done by obtaining flow-proportioned, composited samples every two hours from all pertinent points in the plant. The plant personnel were very helpful in collecting parallel samples for this study. The sampling coincided with normal plant sampling commencing at 7:00 AM on September 23rd and running for 24 hours. Plant operation during this period was considered normal.

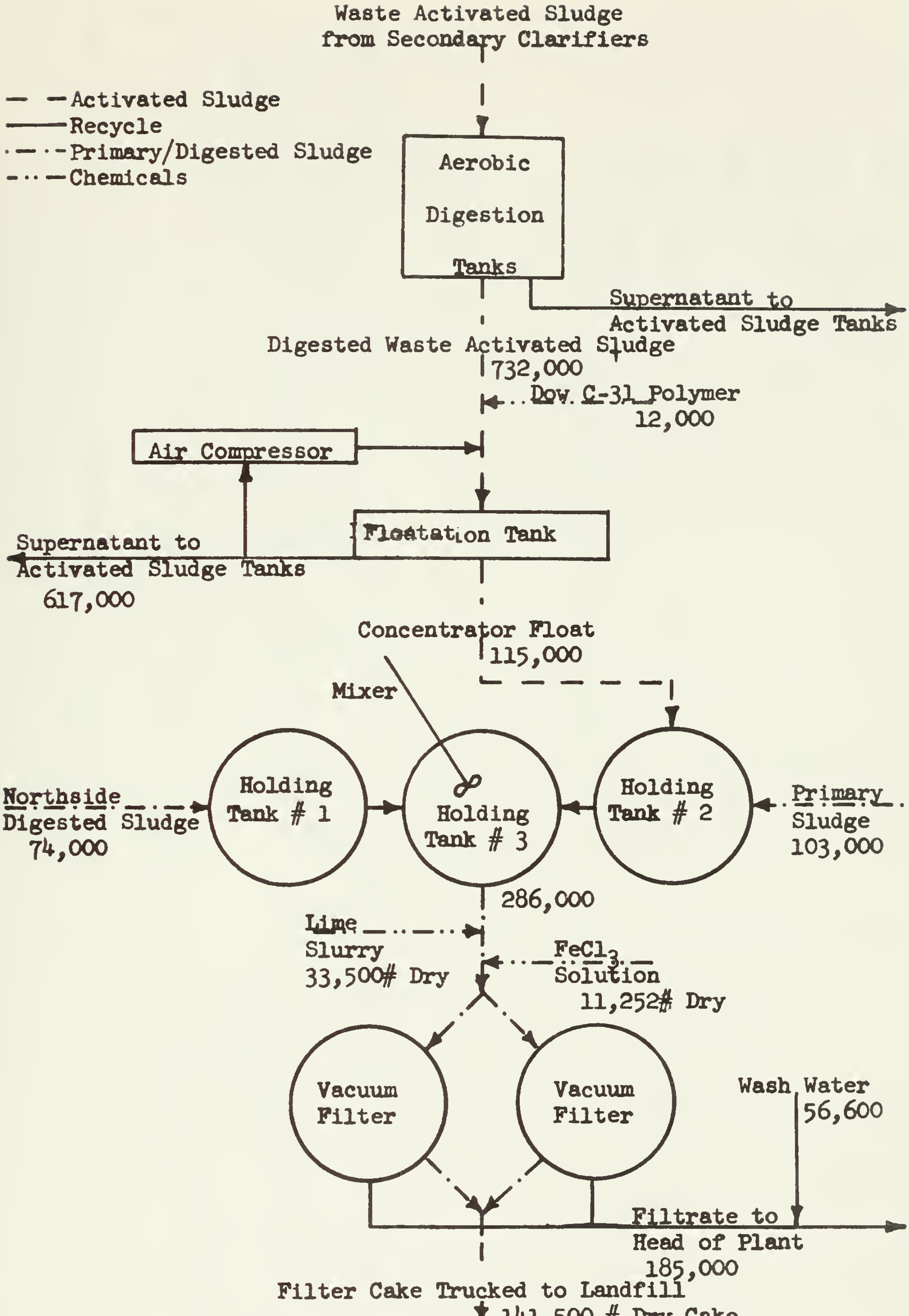


Figure 40. Hydraulic Flow for Sludge Handling at Denver Metro
All values are expressed in gallons per day.

TABLE VII

Plant/Unit Removal Efficiencies for Denver Metro Sewage Treatment Plant																
		Primary Settling Basins					Secondary Clarifiers						Aerobic Digestion Tanks		
Parameter	Comb. Plant Inf. mg/L	Pri. Inf. mg/L	Pri. Eff. mg/L	% of Pri. Inf. Removed	% of Plant Inf. Removed	Settled App. mg/L	Sec. Inf. mg/L	Sec. Eff. mg/L	% of Sec. Inf. Removed	% of Settled Applied Removed	Plant Eff. mg/L	% of Settled Applied Removed	Waste Act. Sludge mg/L	Dig. Waste Act. mg/L	% of Waste Act. Removed
BOD_5	235	180	130	28	45	149	1245	29	97.5	81	21	86	----	904	---
COD	475	362	250	31	47	215	3411	86	97.5	60	77	64	10108	8076	20
TKN	33.5	28.9	25	11	24	25.2	215	18.1	92	28	17.9	29	616	457	26
$PO_4^{=}$	34	28.5	28	2	18	24.5	249	20.5	92	16	15.5	37	830	845	-2
TS	1367	1217	1187	2.5	13	1082	3443	859	75	21	840	22	10915	8435	23
VTS	412	323	286	11	31	382	2197	184	92	52	163	57	8395	5774	31
FTS	955	894	901	-1	6	700	1247	675	46	4	678	3	2520	2661	-6
SS	291	165	75	55	74	113	2588	47	98	58	41	64	8210	4640	43
VSS	218	124	57	54	74	92	2004	35	98	62	32	65	6610	3500	47
FSS	73	41	18	56	75	21	586	12	98	43	9	57	1600	1140	29

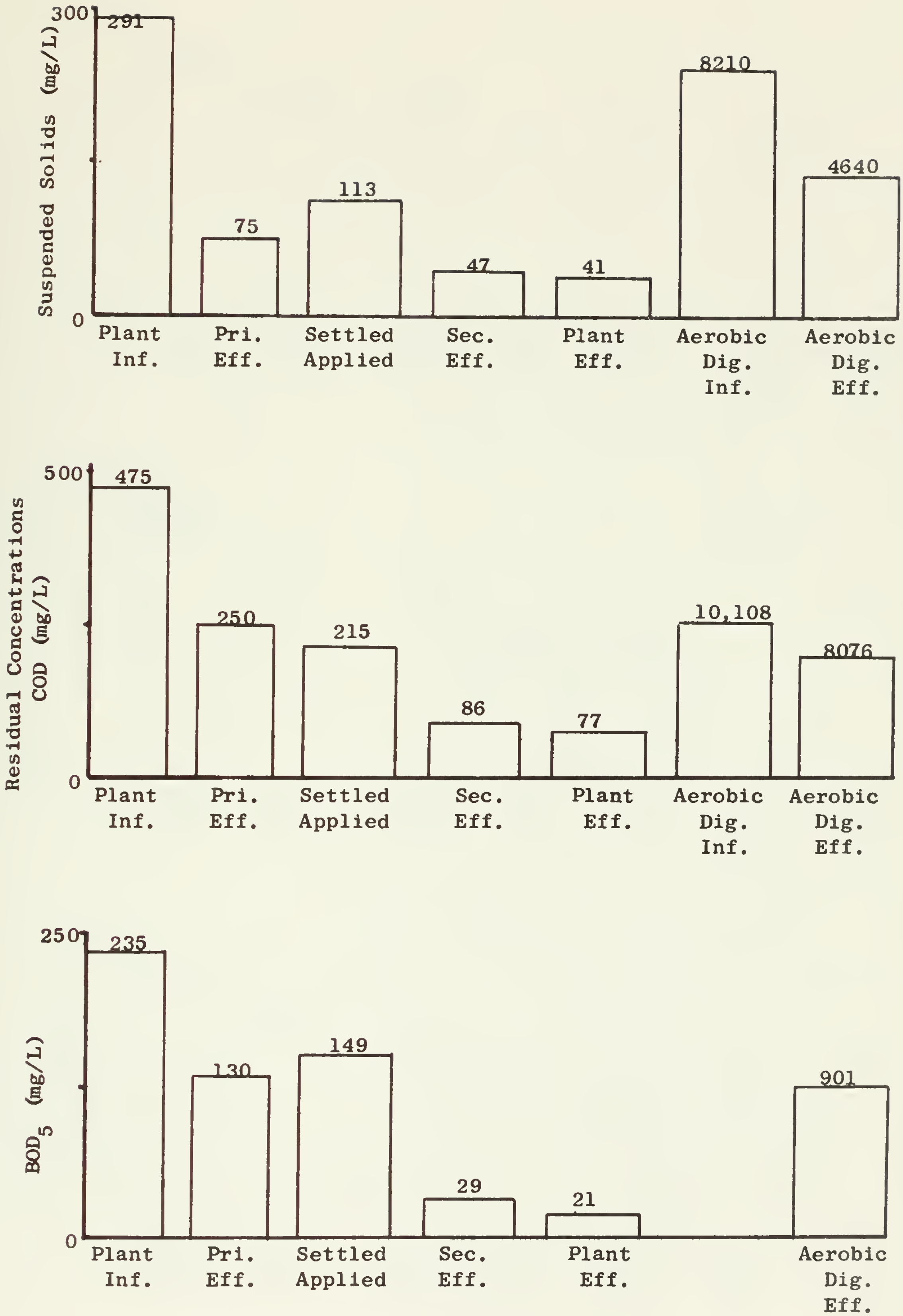


Figure 41. Residual Concentrations for Metro Denver

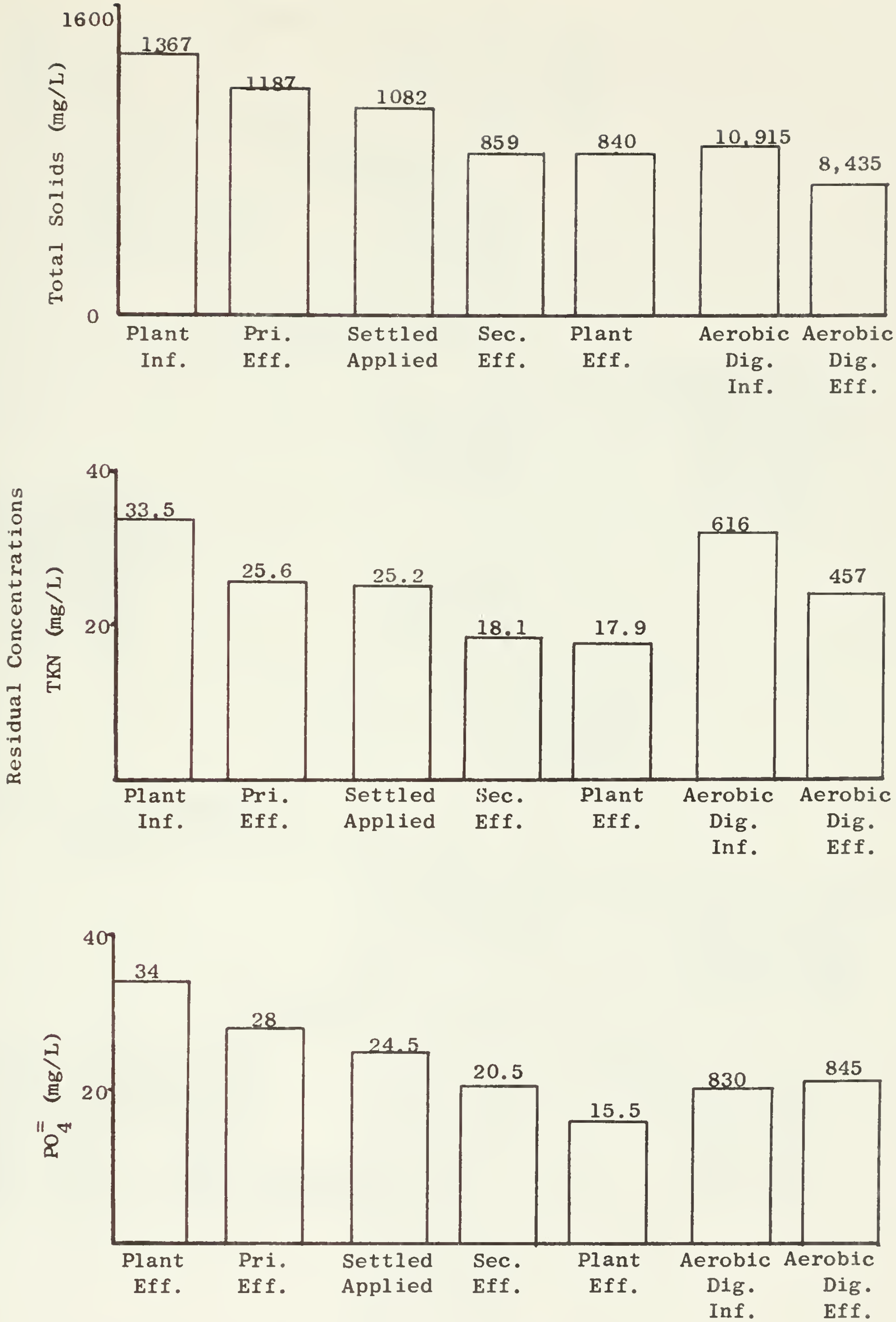
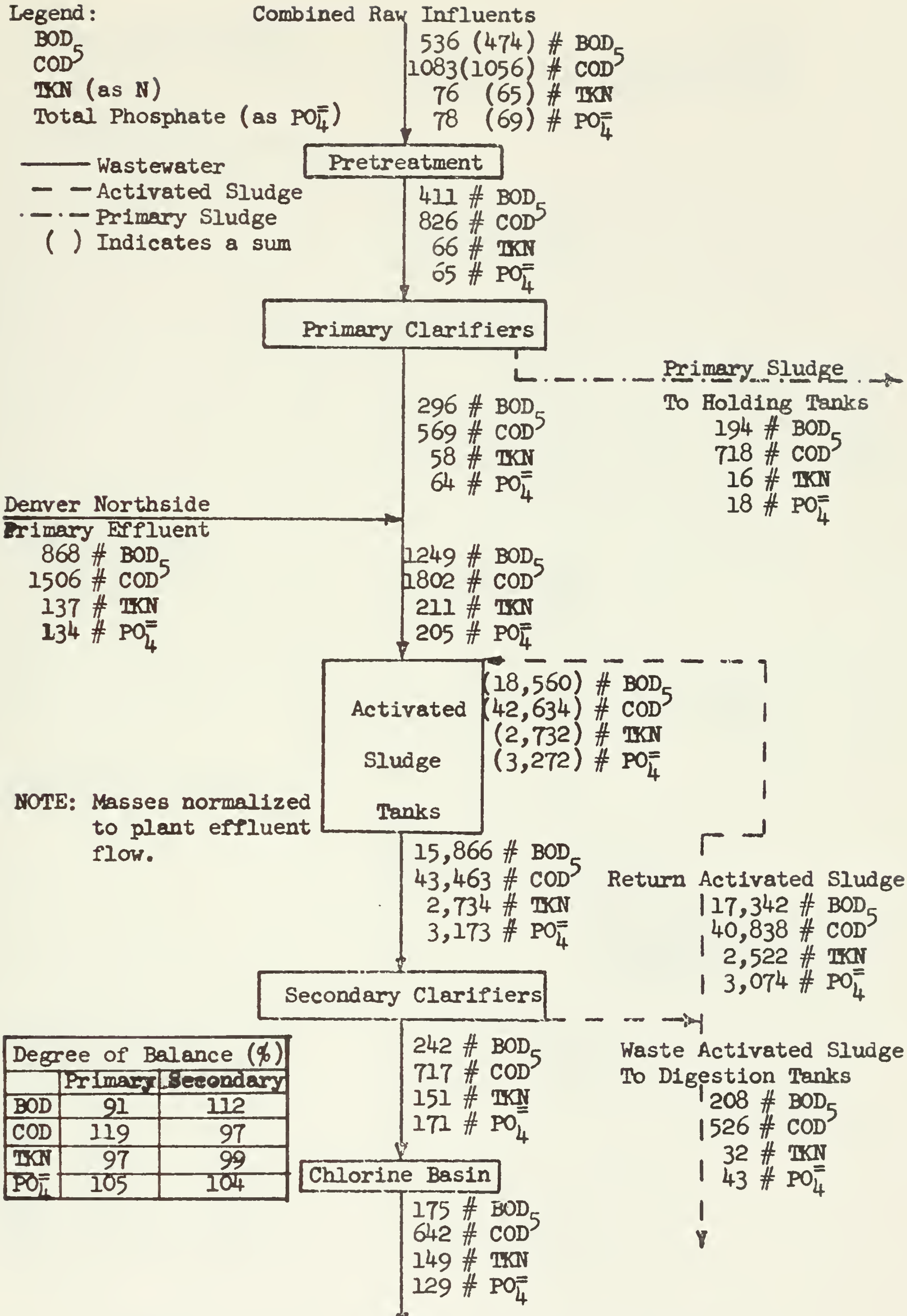
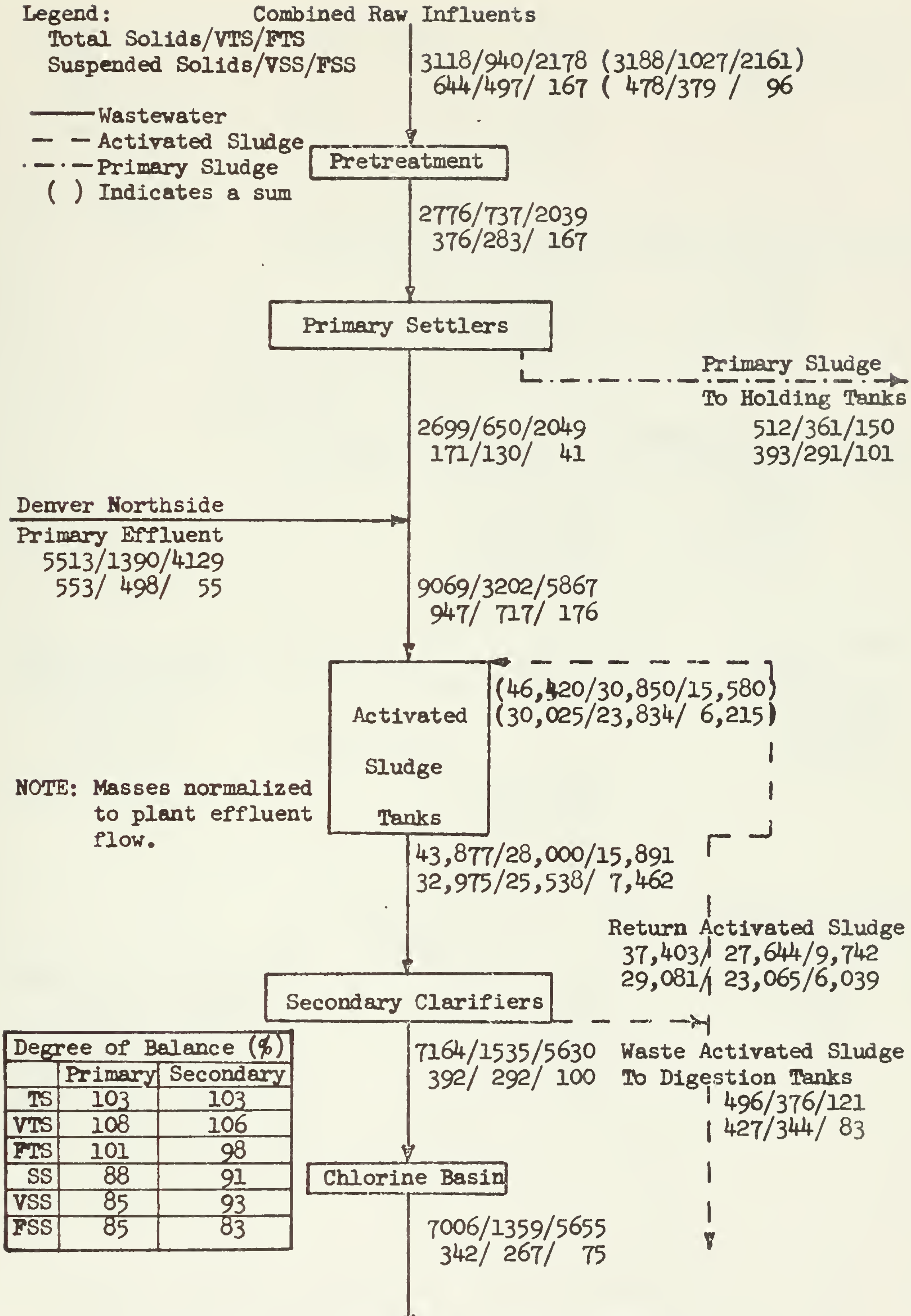


Figure 41. (cont.) Residual Concentrations for Metro Denver



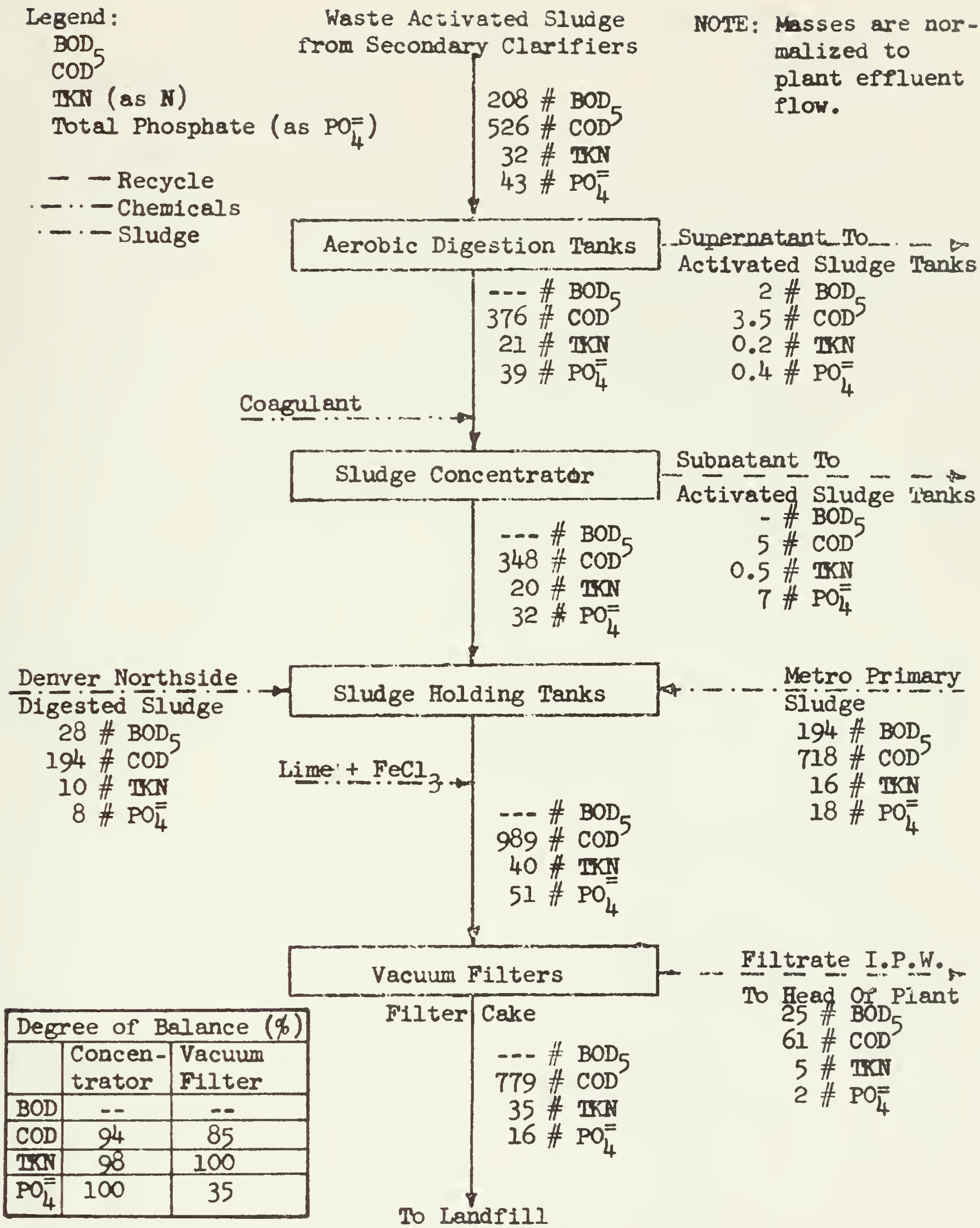
Degree of Balance (%)		
	Primary	Secondary
BOD	91	112
COD	119	97
TKN	97	99
$PO_4^=$	105	104

Figure 42. Material Balance for Denver Metro
All values expressed as pounds per MG plant EFFLUENT flow.



Degree of Balance (%)		
	Primary	Secondary
TS	103	103
VTS	108	106
FTS	101	98
SS	88	91
VSS	85	93
FSS	85	83

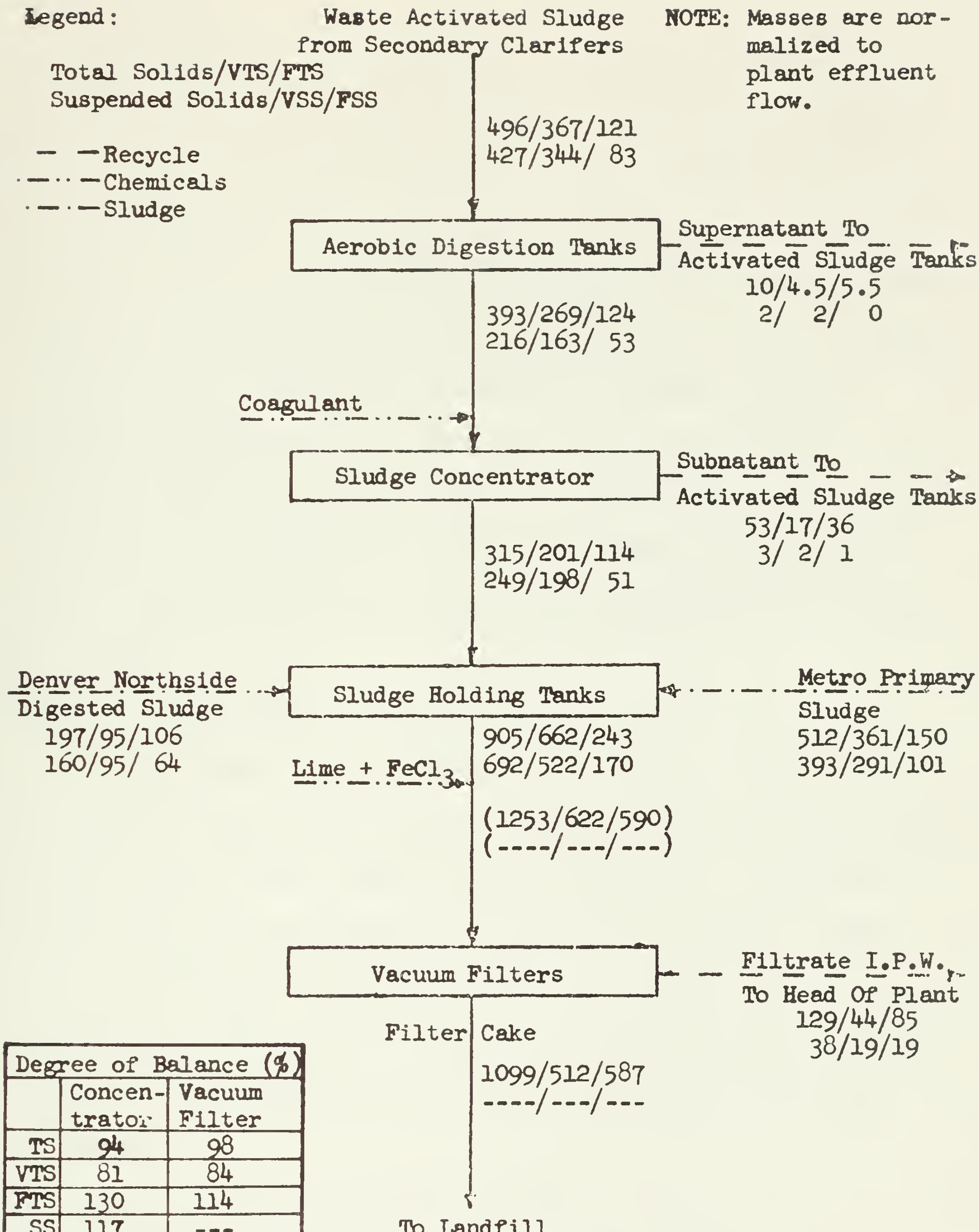
Figure 43. Solids Balance for Denver Metro
All values expressed as pounds per one MG plant EFFLUENT flow.



Degree of Balance (%)	Concentrator	Vacuum Filter
BOD	--	--
COD	94	85
TKN	98	100
$PO_4^=$	100	35

Figure 44 . Material Balance for Sludge Handling at Metro Denver

All values are expressed as pounds per MG plant EFFLUENT flow.



Degree of Balance (%)		
	Concentrator	Vacuum Filter
TS	94	98
VTS	81	84
FTS	130	114
SS	117	---
VSS	123	---
FSS	98	---

Figure 45 Solids Balance for Sludge Handling at Metro Denver

All values are expressed as pounds per MG plant EFFLUENT flow.

Costs Analysis

Cost information received from the Metro Denver administrators was felt to be very reliable and valuable. Operational treatment costs were 8.5 cents/1000 gallons, and total treatment costs were 11.5 cents/1000 gallons. These costs do not include primary treatment and anerobic digestion for approximately 70% of the flow which comes from the Denver North Side Treatment Plant. It did not appear readily evident from the cost breakdowns in Appendix III that economies of scale savings were obtained for operational costs or costs per pound of pollutant removed. Capital construction costs, however, provided major economy of scale savings. Appendix IIIb shows savings of two times or greater for capital costs per average MG treated.

Discussion of Results--Testing Comments

1. The large number of sample points at Metro Denver exceeded the number of BOD_5 tests that could be run. Packaging plant influent, waste activated sludge, waste activated supernatent, concentrator subnatent and vacuum filter feed were points not tested for BOD_5.

2. The "pre-grit influent" sample had higher parameter concentrations than either the "primary influent" sample or the combined inputs of the three raw sewage sources. See Appendix X for data comparisons.

Discussion of Results--Concluding Comments

1. There was some degree of correlation between the removal of BOD_5, COD, and suspended solids. In the primary tanks, suspended solids were removed to a greater extent, and in the aeration tanks a greater percent of BOD_5 was removed, as might be expected. See

Figure 41. for a graphical presentation of this data. BOD_5 oxidized during chlorination occurred at the rate of 3.45# BOD_5/#Cl_2 and COD at the rate of 3.9# COD/#Cl_2.

2. Material balances on the primary settlers and secondary clarifiers ranged from 88% to 119% of the material accounted for. In the sludge streams, balances for the concentrator and vacuum filter ranged from 85% to 117% of the material inputted, except for the $PO_4^=$ balance on the filter where only 35% of the material was accounted for.

3. There was no oxidation of TKN in the aeration tanks. This was due to the short detention period of two hours. 33% of the TKN going to the aerobic digester was removed. This was the only removal of TKN in the plant, other than by removal in the solids. No nitrate test was run on the nitrate and nitrate effluent to see if oxidation was the TKN removal mechanism, but tests run by the Metro Denver laboratory on digested waste activated sludge showed concentrations between 30 mg/L and 50 mg/L.

4. Poor balances around the vacuum filter were obtained when a figure of 10 tons wet cake per load hauled away was used. A figure closer to 8 tons wet cake per load gave better results and was used in all calculations.

5. Conversion of BOD_5 and COD to CO_2 and biomass was not computed.

CHAPTER V

CONCLUSION

This chapter is separated into three parts: a compilation of the data and results previously discussed producing expected plant performance from three types of sewage treatment plants; cost analysis; and statements of basic conclusions, uses, and applicability of material balances in wastewater treatment and wastewater treatment management. General observations will be made on trickling filter, extended aeration, and activated sludge plants separately. The compilation of data, observed and expected for removals for the various units in each plant will produce "typical" material balances of all the parameters studied. The conclusions and applications of material balances will point out shortcomings and show advantages establishing a foundation upon which further application of this "tool" may be used.

Composite Treatment Plants

A trickling filter sewage treatment plant is a difficult type of plant to obtain reliable material balances on in a short period of time. The cause of this difficulty is the trickling filter itself. The rest of a conventional trickling filter plant presents no problems because most of the mass, water and sludges, in the clarifiers is completely exchanged every two or three hours. However, the slime and algal growth on the media of trickling filters can be retained within the filter for extended and unknown periods of time before it drops off and washes away. Many variables can affect the time it takes for this to happen. It is this indefiniteness in a continuously changing situation which precludes rapid and accurate

evaluation of material balances in a trickling filter. Over a long period of time, what goes in, will come out. In between these periods, the filter can act as a warehouse collecting nutrients and some mass before it discharges the same. So it is best to sample over a period of time sufficient to insure at least one accumulation/sluff cycle has occurred. It is with this cautioning idea that the use of the information provided by the "typical" trickling filter plant given below should be used.

TABLE VIII--Ranges of Removals in Trickling Filter Plants (%)

<table>
<tr><th>Parameter</th><th colspan="2">BOD</th><th colspan="2">COD</th><th colspan="2">TKN</th><th colspan="2">$PO_4^{=}$</th><th colspan="2">Tot.Sol.</th><th colspan="2">Sus.Sol.</th></tr>
<tr><td>Plant Unit</td><td>Obs.</td><td>Exp.*</td><td>Obs.</td><td>Exp.</td><td>Obs.</td><td>Exp.</td><td>Obs.</td><td>Exp.</td><td>Obs.</td><td>Exp.</td><td>Obs.</td><td>Exp.</td></tr>
<tr><td>Primary</td><td>30-40</td><td>32-44</td><td>30-40</td><td>---</td><td>5-15</td><td>---</td><td>5-15</td><td>---</td><td>10-15</td><td>---</td><td>45-55</td><td>55-64</td></tr>
<tr><td>Trickling Filter</td><td>30-40</td><td rowspan="2">77</td><td>30-40</td><td>---</td><td>10-20</td><td>---</td><td>0-10</td><td>---</td><td>0-5</td><td>---</td><td>5-15</td><td>---</td></tr>
<tr><td>Secondary</td><td>10-20</td><td>10-20</td><td>---</td><td>5-15</td><td>---</td><td>0</td><td>---</td><td>0-5</td><td>---</td><td>10-20</td><td>---</td></tr>
<tr><td>Overall</td><td>75-85</td><td>65-85</td><td>75-85</td><td>65-85</td><td>30-40</td><td>---</td><td>15-20</td><td>---</td><td>10-25</td><td>---</td><td>60-90</td><td>80-90</td></tr>
</table>

*Expected values taken from (19).

Expected removal efficiencies sought for other than BOD_5 and suspended solids in wastewater literature was almost nonexistent. The observed removal efficiencies in Table VIII are "best estimate" values. "Best estimate" values took into consideration normal plant operation, actual to design load ratio, and reliability of data. The "typical" composite trickling filter plant has an average influent load per one MGD placed on it. See Figure 46.

Three conclusions are made regarding trickling filter plants. The conclusions were reached because of the application of material balances on four different trickling filter plants. Several of the conclusions were obvious with just a cursory look at the material balances. It was questioned whether one or two balances would relay any valuable information which could be used to improve plant efficiency. In all cases though, the material balances provided insight into plant operation, and therefore, knowledge towards the efficient use of the treatment plant.

1. Recycle in a trickling filter plant should be used to keep a constant organic load on the filters as removal has been found to be independent of volume of flow and concentration of waste (21). This organic loading is usually done by increasing the recycle during low flows or when the waste is weak. This is often done in trickling filter plants by passing the recycle through the primary settler. See schematic flow diagrams of the Broomfield and Colorado Springs plants. Proportionately, very little suspended solids is removed by this recycle flow through the settler. The more efficient use of recycle would be to recycle directly back on to the filter thereby removing part of the hydraulic load on the primary settler.

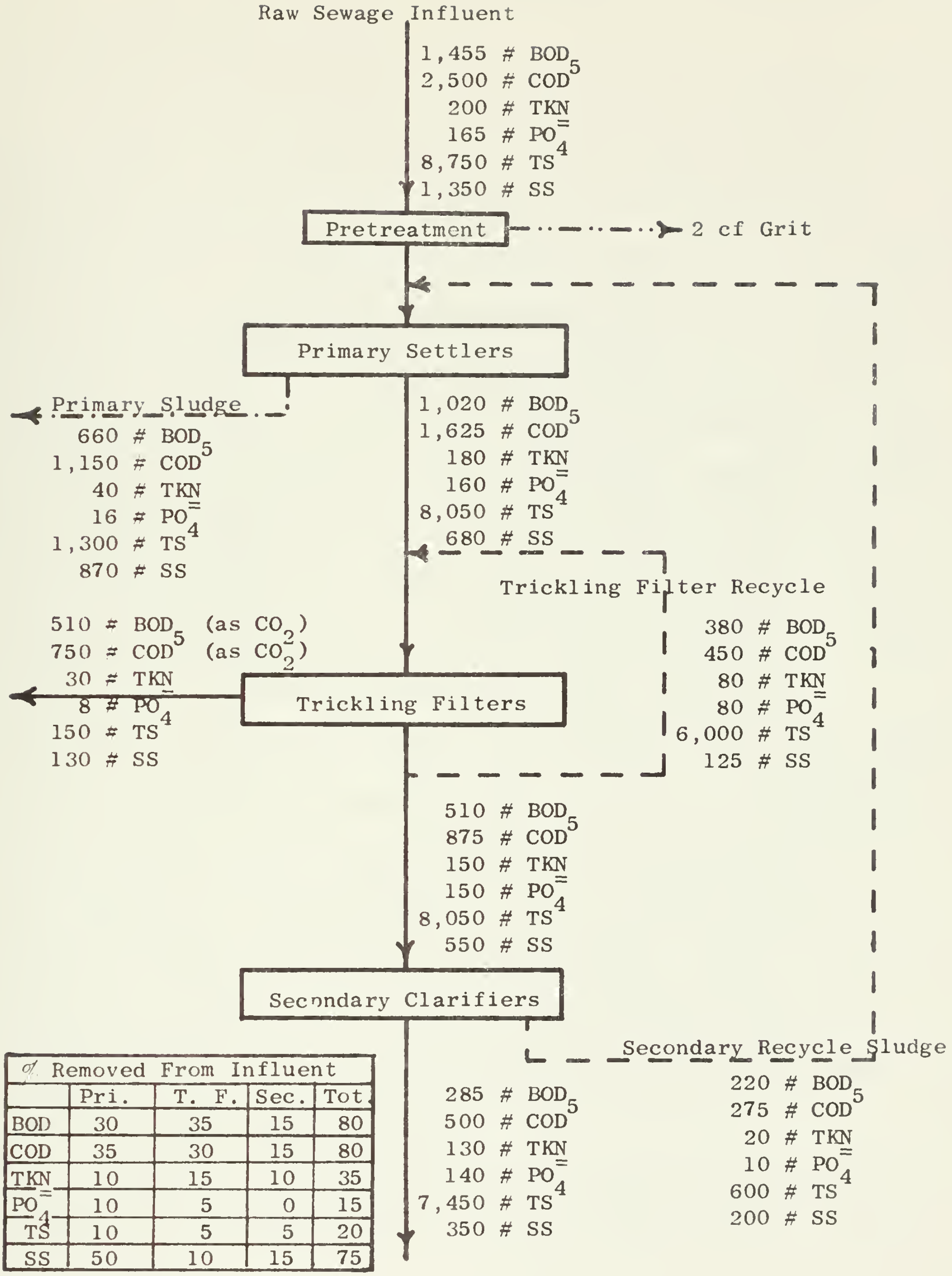
2. In the trickling filter process, a minimal amount of sludge is produced. A trickling filter plant operator does not have to worry about a sludge blanket raising above the secondary clarifier weirs. As indicated in this study, the secondary return sludge is usually a weak waste stream. The fact that the stream is relatively weak suggests that if the volume of recycled sludge could be reduced, but still carry the same mass of sludge, the net effect would be a

reduced hydraulic loading throughout the plant, and a probable increase in plant efficiency. Recycle through a primary clarifier should be minimized and used solely to remove suspended solids.

3. The trickling filter plant is a rather static phenomenon. The biological treatment mechanism, the zoogloea mass, cannot be altered greatly. Only the rate of load application to the mechanism and the time the waste is in contact with this mechanism can be varied. Also, this form of biological treatment is at the mercy of the elements. In total, it adds up to the fact that a trickling filter plant has a minimum of external control and flexibility with which to effect optimum removal efficiencies.

Activated sludge plants presented a different type of problem in obtaining good material balances. The problem concerned test accuracy for the more concentrated waste streams. It was difficult to get representative samples because of the large dilution factors used and the lack of homogeneity of the suspended material. This difficulty was especially evident in balances concerning the aeration tanks. A composited, "typical" extended aeration plant and activated sludge plant are given below with mass distribution of the waste parameters studied.

Review of the data gathered for activated sludge plants indicates that a higher degree of total phosphate removal occurs in these plants. On an average, 15% more phosphate (as $PO_4^{\equiv}$) was removed by activated sludge than trickling filter plants. As for total Kjeldahl nitrogen, no appreciable removal difference between higher rate activated sludge processes and trickling filter plants could be found. Only the Snowmass plant showed a significantly higher



% Removed From Influent

	Pri.	T. F.	Sec.	Tot.
BOD	30	35	15	80
COD	35	30	15	80
TKN	10	15	10	35
$PO_4^=$	10	5	0	15
TS	10	5	5	20
SS	50	10	15	75

Figure 46. Composite Trickling Filter Plant

removal, 80% versus 35%. This was probably due to varying flows and long pond detention periods.

The large amount of solid mass produced in an activated sludge plant places a heavy responsibility on the secondary clarifier to perform its function. A small release of mixed liquor suspended solids can carry a large part of the waste mass with it. The second study period, August 17-18, at the Snowmass plant, is an excellent example. Solids were passing over the secondary effluent weir for approximately three of the 24 hours sampled. The removal efficiency of plant influent raw waste dropped 35% for BOD_5, COD, TKN, and $PO_4^{=}$, and 95% for suspended solids, between the first study period and second study period. In terms of mass, 4.5 to 5 times as many pounds of BOD_5, COD, and TKN were sent to the polishing pond. Ten times as many pounds of suspended solids were sent. Refer to Figures 35. through 38. in Chapter IV. The Metro Denver plant would show a higher removal efficiency except that it was noticed during sampling that clarifier scouring occurs during peak flow periods. The importance of adequate design of the secondary clarifier in an activated sludge plant cannot be overemphasized. This is a critical unit in an activated sludge plant because a large mass of waste pollutant carried by activated sludge can pass over the effluent weirs in a short period of time.

An activated sludge plant is more flexible, with respect to operating conditions and treatment media, than a trickling filter plant.

1. The concentration of the mixed liquor suspended solids can be varied by the volume of activated sludge returned.

% of Influent Removed	Aer.+Sec.	Pond	Total
BOD	75-85	10-15	85-95
COD	75-80	10	85-90
TKN	35-45	0-5	40-50
$PO_4^=$	25-35	0	25-35
TS	30-35	5-10	35-45
SS	65-85	15-20	90-100

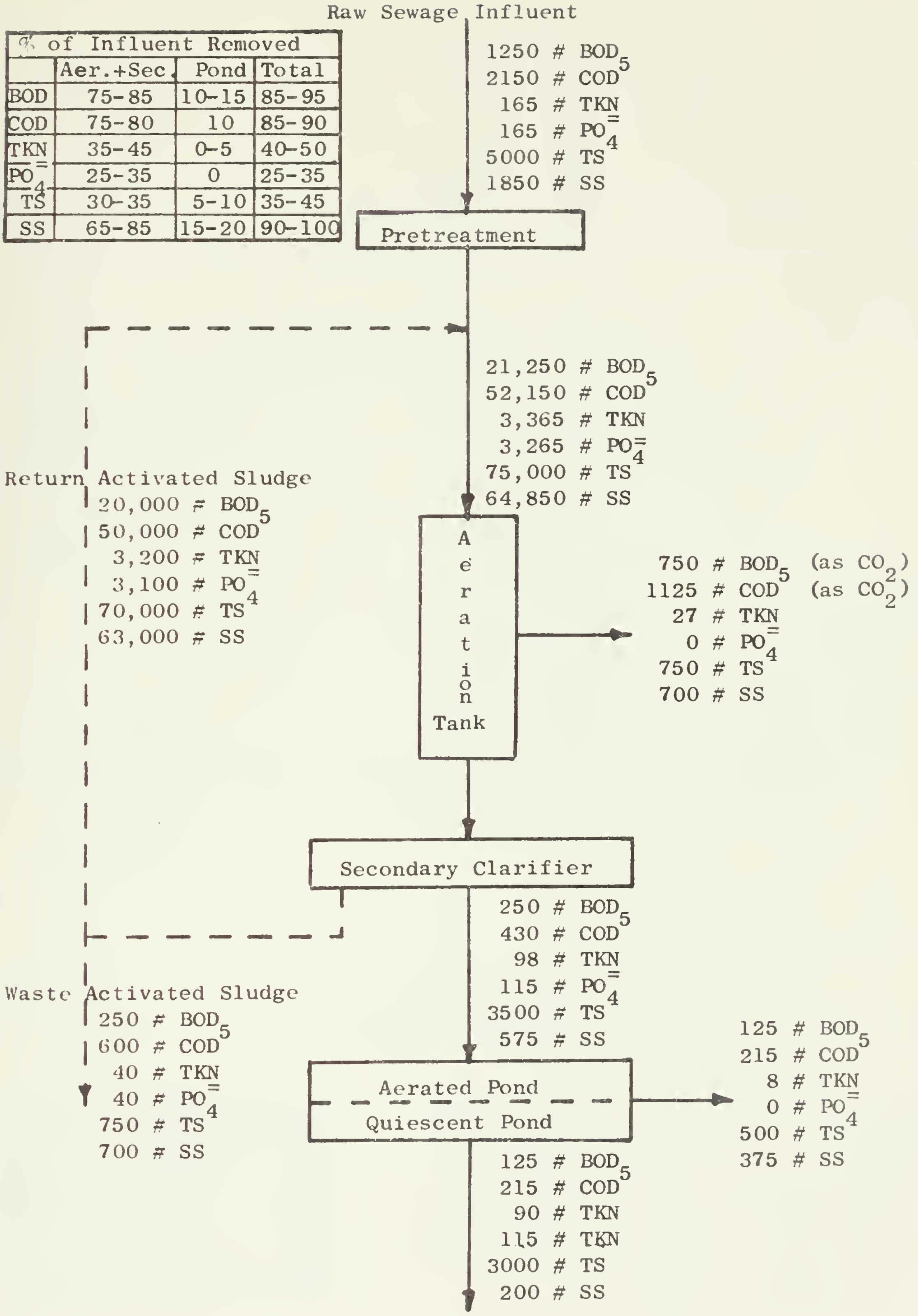
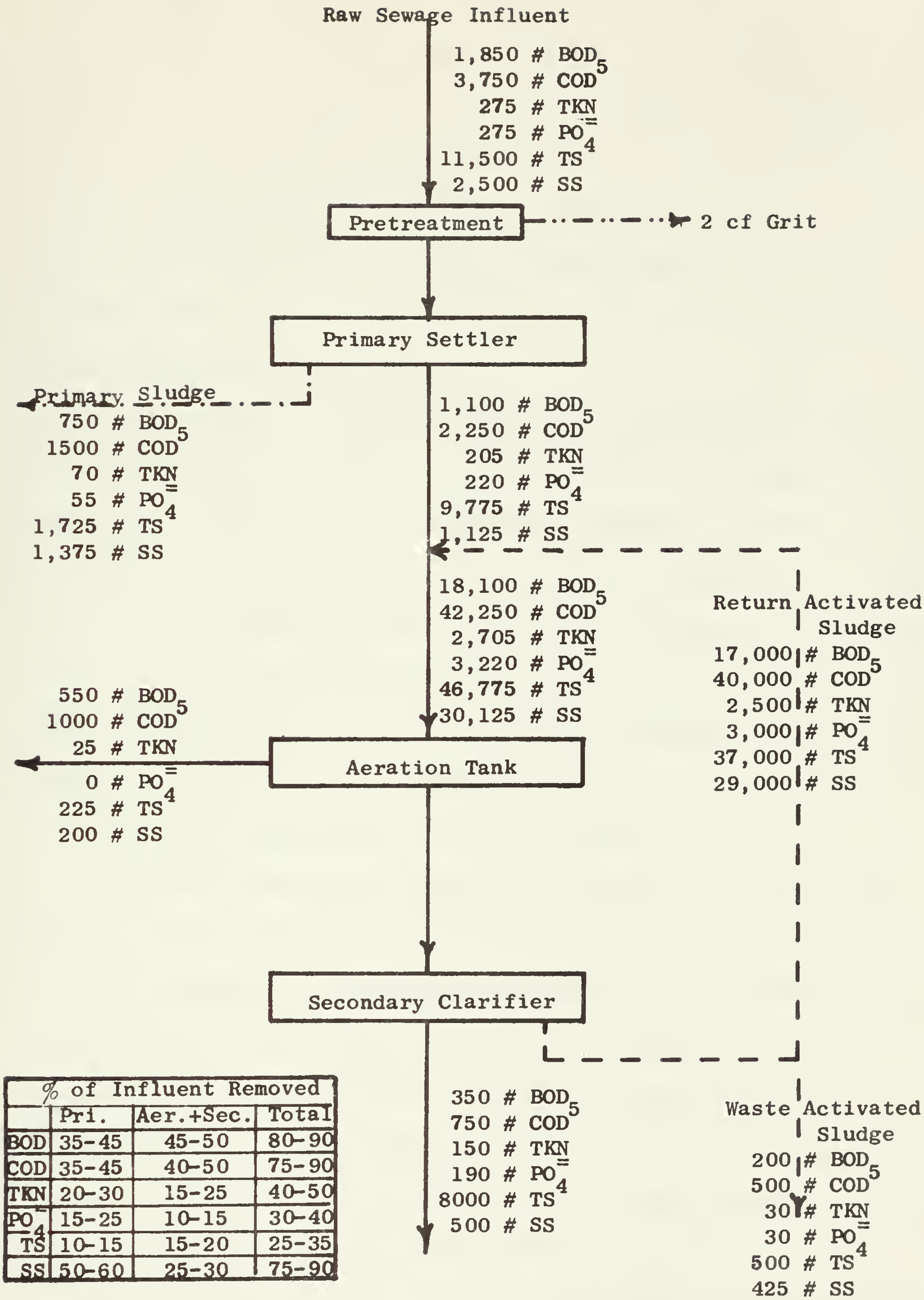


Figure 47. Composite Extended Aeration Plant per 1 MGD Influent



% of Influent Removed			
	Pri.	Aer.+Sec.	Total
BOD	35-45	45-50	80-90
COD	35-45	40-50	75-90
TKN	20-30	15-25	40-50
$PO_4^=$	15-25	10-15	30-40
TS	10-15	15-20	25-35
SS	50-60	25-30	75-90

Figure 48. Composite Activated Sludge Plant per 1 MGD Influent

2. Waste activated sludge volume can be changed.

3. The nature of the activated sludge can be modified. A contact stabilized sludge or a nitrifying sludge can be produced. To use this flexibility advantageously and with knowledge requires regular monitoring of all variables. A material balance is a useful tool in taking full advantage of the flexibility in an activated sludge plant.

Costs Analysis and Conclusions

In an attempt to relate treatment plant operational qualities with different costs analysis, comparisons were made between costs and several treatment plant parameters. Cost data collection, data reliability, and data availability were all very divergent. In order not to use information erroneously, as much background as possible is given to define the numbers obtained. Analysis included economies of scale, relative costs of distinct units in each plant, and pollution removal costs for different type plants.

1. Current Operational and Capital Costs

Each plant manager was querried for average operational costs. The costs were obtained for the most recent accounting period prior to time of sampling. Boulder and Baker plants provided data from the previous month, Denver and Snowmass plants the previous year, Broomfield the first six months of 1971, and Aspen and Colorado Springs plants the previous nine months. The most detailed operational costs included: personnel salaries, vehicles, utilities, disposal, chemical, and maintenance and repair costs. It was believed that no two plants defined the above subdivisions completely the same way. Also requested from the plants were capital costs

subdivided into bonded indebtedness and contractual obligation for plant construction. The operational and capital costs were reduced to costs per average million gallons of wastewater treated. This information is provided in Appendix IIIa.

2. Costs per Pound of Pollutant Removed

The second analysis compared the operational and total costs of the different type plants to the removal of a pound of the different pollutants studied. The use of this information should include a complete treatment plant background such as: the type of plant, operating to design ratio, and how well the plant was operated by the personnel in charge. Cost comparison is dependent on these variables. The "# removed" in Appendix IIIa was computed by taking the material balance difference between the influent load and effluent value, irregardless of the degree of total plant balance of that pollution parameter. Operational costs per pound removed was simply the ratio of operation costs compiled earlier; and the #'s removed per MG influent flow. Total costs per # removed was the sum of operational and capital costs per # removed per MG.

3. Capital Construction Costs for Plant Units

Capital construction costs were sought in an attempt to further break down the costs applied to each unit within a plant. The capital construction cost values were taken from anywhere between initial engineers bids to the final constructions costs and are presented in Appendix IIIb. The year for which the information was obtained is also given. Breakdown into costs applied to the respective units was only available from the Metro Denver plant. Engineers bids are not generally broken down into costs for the

various units. Where only the bid information was available, a percentage of the total costs was taken for each unit. This had to be done with the Boulder, Aspen Metro, and Snowmass plants.

4. Operational Costs per Plant Unit

Operational and/or capital costs breakdown for each unit (primaries, aeration tanks or trickling filters, and secondary clarifiers) is nearly impossible information to obtain. Only Metro Denver had this type of breakdown. See Appendix IIIc.

From Appendix IIIa, the following cost approximations were made:

1. BOD_5, total solids, and suspended solids costs were $0.05 to $0.10/MG per pound pollutant removed.

2. COD costs were $0.033 to $0.045/MG per pound pollutant removed.

3. TKN and $PO_4^{=}$ costs are more variable due to the accumulation and release of nutrients in plants. In general, TKN varied from $0.82 to $1.70/MG per pound pollutant removed. $PO_4^{=}$ costs varied from $1.60 to $3.20/MG per pound pollutant removed, or about twice the cost of TKN removal.

Colorado Springs and Snowmass operational cost data was believed of questionable value.

Appendix IIIb shows a breakdown of capital construction costs.

Construction costs available for Boulder and Metro Denver plants showed:

a) 10 to 15% of total costs went to primary settling tanks,

b) 45 to 55% of total costs went to combined secondary treatment (aeration tanks or trickling filters and secondary clarifiers), and

c) 32% to sludge disposal.

The total capital construction costs for all plants, except Baker and Colorado Springs, were adjusted to 1969 prices by the Engineering News-Record quarterly Construction Cost Index (24). Yearly capital costs were computed from the total 1969 cost by applying a capital recovery factor of 6% for 25 years. It was also assumed that the plant value depreciated at a rate of 4% for 25 years with negligible salvage value at the end of this period. An average yearly flow over this 25 year period was computed by assuming the average flow was one half the design flow for the whole period. Capital costs per average MG flow and depreciation costs per average MG flow were two to three times less expensive for the Metro Denver plant than for any other plant studied.

Costs, operational and/or capital, applied to each unit in a plant is HIGHLY subjective, and of questionable value in this study. More detailed, in-progress research is needed to define costs for each unit. Actually any past information to be applied to costs per operational unit is probably of less value because this past information relies on the estimates and guesses of operators and supervisors on what percentages of costs and time is devoted to each unit.

Conclusions, Uses, and Applications

The third part of this chapter will state basic conclusions about, uses for, and applications of material balances in wastewater treatment.

It was stated several times in the "Discussion of Results" sections in Chapter IV that the BOD_5, COD, and suspended solids percent removal efficiencies correlated very closely. This

phenomenon can be put to use if material balances have defined what to do for various situations. Suppose an automatic sampler has collected a sample for several hours, and a rapid Jeris COD test or a suspended solids test indicates that the waste has been very weak over that period. It is known from previous material balances that for a weak load, the plant should be operated a specific way to produce optimum removal. This could be an example of how a material balance defined what was happening and how it could be put to use. The conclusion to be made here is that BOD_5, COD, and suspended solids removals correlate, and because they correlate, advantage can be taken of this fact, such as using one test to define all three parameters.

Two circumstances for which material balances can be used are discussed briefly below.

A series of material balances conducted during the summer months compared with another series of material balances during the winter months would give valuable information as to what affect extremes in weather conditions had on the treatment plant. The results of the comparison of the two balances could influence future design considerations.

A material balance or analysis is a more representative basis for a rate charging structure for the treatment of wastewaters. Neither flow volume or waste concentration, used separately, are indicative of the actual load placed on a treatment plant. Large volumes of highly concentrated wastes place a greater load on a treatment plant than an equal volume of waste at a much lower

concentration. A rate charging structure should charge all users equally for the respective loads placed on a treatment plant.

Another conclusion is that even a single balance can provide valuable information on how a plant works. The largest asset of a single balance is defining what should be called the secondary streams in a treatment plant. They are the recycle and return streams as opposed to the main streams, which are fairly well investigated and understood. The most obvious benefits in this study from just one or two balances at a plant were: the dilute nature of recycle sludge from trickling filters, and the fact that the Porteous process returns 1/3 of the wastes sent to it.

Material balances conducted in this study point out the inadequacies of flow metering in most plants. Only the major wastewater streams were metered regularly and with some degree of accuracy. The use of more extensive flow metering in plants to enhance the understanding of a plant's operation is recommended from the experiences in this study.

Small volume, concentrated wastes such as digester decants and vacuum filter filtrates can materially increase the load on a treatment plant. Serious consideration should be given to treating these smaller volumes separately by a physical-chemical process and thereby increasing the efficiency of a plant. It would cost additional money for this separate process, but not as much as increasing a whole treatment plant to treat a comparable load.

BOD_5 and COD test results, and material balances on sludges, proved very difficult to obtain accurately. All that can be confidently stated about BOD_5 and COD test concentrations is their

order of magnitude. Sludge volumes were equally difficult to ascertain, and they added to the BOD_5 and COD balance inaccuracies. Many of the errors or unaccounted for masses in several of the material balances could be reduced by increasing the number of balances made, and by closer and more accurate measurement of flow volumes.

A treatment plant is subjected to continuously varying flow concentrations and volumes. A material balance on a plant over a period of time can supply information regarding how the plant works under all these conditions. It can also provide information on what steps are necessary to maximize removals under all these conditions. The knowledge of how a plant will react and what to do under various circumstances to get maximum removals can be of great benefit. The benefit can be reached by a continuous monitoring of the influent waste using some rapid parameter determination. The results of the monitoring would dictate how the plants should be operated to effect optimum removal.

Another use of the application of material balances to increase treatment plant efficiency is when tertiary treatment plants are employed for additional treatment after the conventional secondary plants. More tertiary plants are being envisioned and built all the time. These plants will treat the effluents of the secondary plants.

The treatment capability of a tertiary plant is directly dependent on the influent waste. If the influent waste is weak, the tertiary effluent will be good. If the influent waste is concentrated, tertiary effluent will not be as good. It has been found (22), for instance, that each carbon column in a series will remove about 50% of certain wastes applied. Also, designed rapid sand

filter media is inadequate when the concentration of suspended solids in a waste stream increases over that for which the media was designed. Both of these examples illustrate the importance of quality, conventional treatment plant effluent. The point to be made here is that if a conventional treatment plant is made more efficient, and if this effluent is to receive tertiary treatment, the tertiary plant will not have to have as large a capacity to produce the same final effluent. The costs in improving conventional plant efficiency could well be less than the costs of a larger tertiary facility, resulting in an overall net savings.

One of the questions asked about any investigative study is where does this lead us, and the question asked earlier in this report was how can a material balance be used to increase the efficiency of existing plants? Both questions can be answered by the ideas discussed below, ideas which are totally subjective, but possibly answer the question of how material balances can be used. The basic idea is to make use of modern technological capabilities with the application of material balances to increase the removal efficiencies of sewage treatment plants. The overall idea is best described in a thought flow diagram shown in Figure 49 .

A material balance is used to gather data about a plant. This data, plus other information, is put into a plant simulator program to generate output data on the effluent streams. If this generated data agrees with the material balance data, the simulation program can reproduce more plant output data. If not, the simulation program is modified until it does agree with actual plant output. Once the simulation program describes the existing plant, the plant

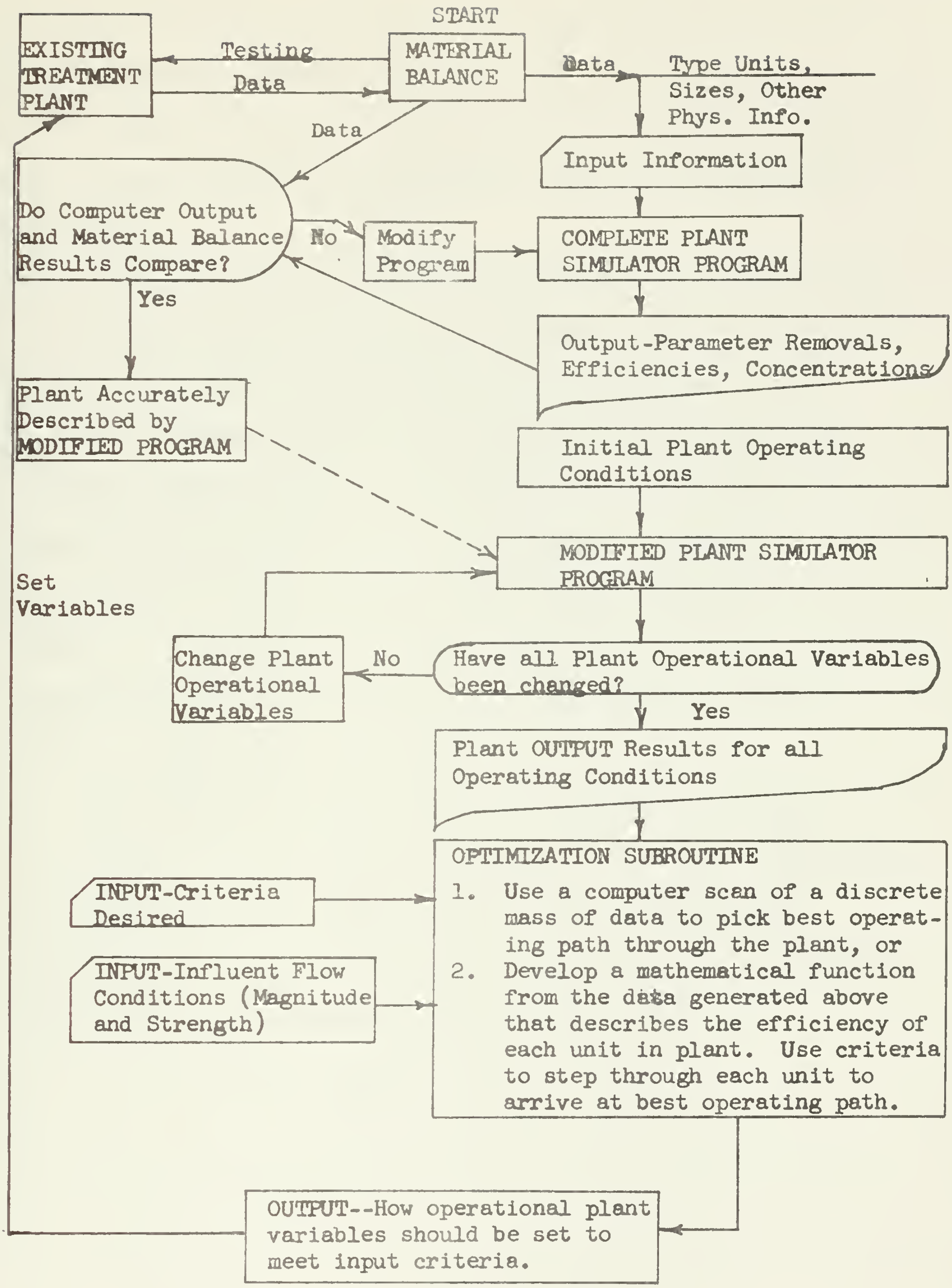


Figure 49. Plant Simulation/Optimization Flow Chart

operational variables (recycle flow, sludge drawn off, air supply rates, hydraulic loading, etc.) are varied for all possible influent waste water conditions. The output data for each influent condition and for each combination of operational variables is stored for future use.

An optimization program is used at this time. Criteria to be met, such as most BOD_5 removed, and influent flow conditions at the time optimization is desired are read into the program. The optimization program utilizes the simulator program output data computed earlier, applies the criteria desired and influent flow conditions, and outputs how the plant operational variables should be set. How the optimization program uses input data and criteria to arrive at a solution is not expanded upon herein. Setting the plant operational variables determined by the optimization program will, hopefully, obtain the criteria desired.

This imaginative idea could be used to improve removal efficiency or increase plant capacity, either of which would increase the return on the investment in a wastewater treatment plant. Material balances are the "tool" that provides better understanding and more efficient wastewater treatment plants.

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APPENDIX I

Plant Variables for Trickling Filter Plants

Location / Sampling Period / Date	Hydraulic Flow		Recycle Flows				Water Temp.	Air Temp. F			Detention Time				Organic Load		Hydraulic Load	Effluent D.O.	Effluent pH
			T. F. #1 / T. F. #2		Secondary Sludge						Primary		Secondary				T. F. # 1 / T. F. # 2		
	Actual MGD	Q_A* / Q_D	Actual MGD	R / Q_A	Actual MGD	R / Q_A		Maximum	Minimum	Mean	Act. Hours	T_A / T_D	Act. Hours	T_A / T_D	# BOD_5 / 1000 cf / Day	# COD / 1000cf / Day	MGD Influent / Acre-Day		
Boulder Period I June 16, 1971	6.64	1.28	4.1	.62	.8	.12	66	84	62	76	2.16	.78	2.16	.78	29.2	56	8.1	5	7.1
Boulder Period II June 24, 1971	8.04	1.55	2.67	.33	.8	.10	67	80	65	71	1.79	.65	1.79	.65	33.4	52	9.7	6.0	7.3
Broomfield Period I July 21,1971	0.93	.54	0.15 0.79	0.16 0.84	.4	.43	66	86	63	74	3.7	1.13	3.7	1.13	31.1 56.2	80.6 118.7	8.06 9.17	6.7	7.9
Broomfield Period II July 29, 1971	0.96	.56	0.15 0.79	0.16 0.84	.4	.41	65	73	60	67	3.71	1.14	3.71	1.14	50.8 57.8	90.7 109	8.35 9.5	7.2	8.0
Baker Period I Aug. 23, 1971	1.01	1.01	0.86	0.86	.132	.132	64	87	63	75	2.02	1.01	2.02	1.01	87	105	8.02	6.3	7.4
Baker Period II Aug. 27, 1971	0.98	0.98	0.89	0.89	.132	.132	64	81	65	73	2.08	1.04	2.08	1.04	61.3	102	7.79	6.5	7.5
Colorado Spgs. Period I Oct. 28, 1971	18.9	1.57	6.62	0.35	6.62	0.35	60	40	12	25	2.56	0.92	3.17	0.92	96	189	12.29	6.9	7.3

*A=Actual, D=Design

APPENDIX II

Plant Variables for Activated Sludge Plants

Plant Variables A=Actual D=Design (Location / Date / Sampling Period)			Aspen Metro August 11-12, 1971 Period I	Aspen Metro August 17-18, 1971 Period II	Snow-mass August 11-12, 1971 Period I	Snow-mass August 17-18, 1971 Period II	Denver Metro Sept. 23, 1971 Period I
Hydraulic Flow		Actual MGD	0.94	0.969	0.122	0.466	128.77
		Q_A / Q_D	1.3.	1.34	0.38	1.46	1.1
Recycle Flow		Actual MGD	0.685	0.695	0.329	0.329	67.29
		Q_A / Q_D	0.729	0.718	2.7	0.71	0.52
	Aeration Tank	Actual Hours	16.9	16.3	41	10.8	2.07
		T_A / T_D	0.76	0.74	2.63	0.69	0.63
	Secondary Clarifiers	Actual Hours	----	-----	14.3	3.74	1.85
		T_A / T_D	----	-----	2.62	0.69	0.93
	Polishing Pond or Primary Settlers	Actual Hours	92	92	300	86	1.98
		T_A / T_D	1.3	1.3	.4	1.4	.99
Organic Load		$\frac{\#\ BOD_5}{1000\ cf/Day}$	----	-----	4.6	25.6	70.9
		$\frac{\#\ COD}{1000\ cf/Day}$	-----	-----	9.1	39.4	102.0
pH		Raw Sewage	6.9	7.1	7.0	7.1	7.3
		Final Effluent	7.1	7.1	7.1	7.1	7.2
Dissolved Oxygen (mg/L)		Aeration Tank Effluent	1.2	2.0	1.5	1.8	1.5
		Final Effluent	7.9	7.9	7.2	7.2	4.0
Water Tempreature (F)		Raw Sewage	57	57	58	57	61
		Final Effluent	49	49	51	51	63

APPENDIX IIIa

Operational/Total Costs Analysis

Plant Location	Boulder	Broomfield	Baker	Colo. Spgs.	Aspen Metro	Snowmass	Metro Denver
Average Flow/Day	7.5	0.96	1.0	23.0	0.95	0.4	117.5
Operational Costs $/Average MGD							
1. Personnel	42.16	65.50	---	---	57.89	68.50	---
2. Vehicles	5.88	-----	---	---	2.72		---
3. Utilities	5.32	12.72	---	---	33.98	47.90	---
4. Disposal	2.99	-----	---	---	3.79		---
5. Chemical	8.44	4.09	---	---	3.00	41.00	---
6. Maint. & Rep.	----	4.53	---	---	6.95	34.20	---
7. Total Oper.	64.79	86.84	95.00	50.40	108.33	191.60	85.00
Capital Costs $/Average MGD							
1. Bonded	---	70.00	----	---	----	----	29.80
2. Other	---	---	----	---	----	----	---
3. Total Capital	---	70.00	30.00	---	131.55	----	29.80
Overall Total	---	156.84	125.00	---	239.91	----	114.80
BOD_5 # Removed/MGD	1178	1139	1039	1051	1490	1106	1609
Op. $/# Removed/MGD	.055	.076	.091	.048	.073	.173	.053
To. $/# Removed/MGD	---	.138	.12	---	.161	---	.071
COD # Removed/MGD	1932	1952	2229	2069	2884	1774	2076
Op. $/# Removed/MGD	.0335	.0445	.0426	.0244	.038	.108	.041
To. $/# Removed/MGD	-----	.0803	.056	---	.083	---	.055
TKN # Removed/MGD	41	106	55	31	95	142	77
Op. $/# Removed/MGD	1.58	.82	1.73	1.63	1.14	1.35	1.10
To. $/# Removed/MGD	----	1.48	2.27	----	2.53	----	1.49
$PO_4^=$ # Removed/MGD	27	53	30	-34	45	98	45
Op. $/# Removed/MGD	2.40	1.64	3.17	----	2.41	1.96	1.89
To. $/# Removed/MGD	----	2.96	4.17	----	5.33	----	2.55
TS # Removed/MGD	1176	1308	1290	475	2275	1618	2184
Op. $/# Removed/MGD	.055	.0664	.074	.106	.0476	.118	.039
To. $/# Removed/MGD	----	.120	.097	----	.105	----	.053
SS # Removed/MGD	832	1224	869	926	1980	1293	1631
Op. $/# Removed/MGD	.078	.071	.109	.0544	.0547	.148	.052
To. $/# Removed/MGD	----	.128	.144	-----	.121	----	.070

Op.=Operational To.=Total # Removed/MGD= Influent # - Effluent #

APPENDIX IIIb

Capital Construction Costs

Treatment Unit	Denver	Boulder	Aspen	Snowmass	Broomfield
Pretreatment	---	---	45,564	66,720	---
Primary Settlers	2,866,131	216,836			---
Secondary T. F. or A. S.	10,078,911	653,493	273,384	133,440	---
Secondary Clarif.		379,660	91,128	83,400	---
Sludge Disposal	6,035,958	578,539	20,000	20,000	---
Other	---	181,920	45,464	50,040	---
Total	18,981,000 (1)	1,819,000 (1)	475,640 (2)	353,600 (3)	152,344 (4) 323,675 (2)
ENR Conversion factor to 1969	1200/980	1200/980	1200/1200	1200/1035	1200/640 1200/1200
Total Costs Adjusted to 1969 Prices	23,242,040	2,227,350	475,640	409,971	609,320
CRF @ 6% for 25 yrs.	.07968	.07968	.07968	.07968	.07968
Capital Costs/Year	1,851,923	177,475	37,900	32,667	48,551
Designed Flow (MGD)	117	5.2	0.72	0.32	1.7
Peak Flow/Design	2.0	2.0	2.0	2.0	2.0
Ave. Flow = (Design Flow $\cdot \frac{\text{Design}}{\text{Peak}}$	58.5	2.6	0.36	0.16	0.85
Ave. Flow/Year	21,353	949	131.4	58.4	310.25
$\frac{\text{Capital Const. Cost}}{\text{Yearly Ave. Flow}}$ \$/MG/Yr.	43.50	94.00	144.80	280.80	155.75

(1)=1966 Prices (2)=1969 Prices (3)=1967 Prices (4)=1955 Prices

APPENDIX IIIc

Operating and Maintenance Costs/Unit ($/MGD)

Plant	Primary	A. S.+Sec. Clar.	Chlorination	Concentrator	Vacuum Filter
Denver*	11.00	13.00	.89	6.38/ Dry Ton	12.72 Dry Ton

* Taken from Metropolitian Denver Sewage Disposal District No. 1 Treatment Questionaire for 1970.

APPENDICIES IV through X

Summary of data for each of the treatment plants studied is contained in the respective appendix. Included in the summary is the date the sampling took place, the name of the sample point, and the values determined for each parameter by analytical testing. Under each parameter are two columns. The first colume gives the parameter concentration in milligrams/liter determined from labratory tests. The second column labled "LB." represents the pounds mass of a particular parameter at the sample point per one MGD of influent raw sewage flow to the plant, except the Metro Denver plant where "LB." represents pounds mass per one MGD of effluent sewage flow from that plant.

APPENDIX IVa

Summary of Data for Boulder Sewage Treatment Plant
June 16, 1971

Sample Location	BOD_5		COD		TKN		$PO_4^{=}$		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	179	1493	344	2869	17	141	16.6	138	634	5288
Sec. Sl. Number 1	82	41	197	99	16.4	8	15.8	7.9	590	295
Sec. Sl. Number 2	69	35	143	72	14	7	12.3	6.2	541	271
Vac.Fil. Filtrate	1500	21	2660	38	80	1	31	.4	2396	34
Pri. #1 Influent	240	1123	495	2316	14.8	69	---	---	630	2948
Pri. #2 Influent	290	978	344	1610	18.7	87	---	---	684	3200
Pri. #1 Effluent	154	719	219	1023	17.9	84	13.4	63	491	2293
Pri. #2 Effluent	117	546	193	901	16.8	78	16.3	76	530	2475
Tri.Fil. Influent	115	1659	177	2554	16.3	235	14.4	208	508	7330
Tri.Fil. Recycle	82	419	126	644	15.6	80	13.8	71	517	2642
Sec. # 1 Influent	82	383	126	588	15.6	73	13.8	64	517	2414
Sec. # 2 Influent	82	383	126	588	15.6	73	13.8	64	517	2414
Sec. # 1 Effluent	39	163	94	390	12	53	13	54	492	2049
Sec. # 2 Effluent	39	163	94	390	12	53	13	54	492	2049
Plant Effluent	15	124	134	1116	10.3	86	13.4	112	467	3890
Pri. Sl. Number 1	---	---	63,800	699	2023	19	2100	20	51,600	493
Pri. Sl. Number 2	---	---	72,100	689	1904	18	1200	11	46,730	446
Filter Feed	---	---	62,800	1199	1652	32	1200	23	42,900	819
Filter Cake	---	---	871	885	28	29	18.2	19	202,200	1016
Grit	---	---	660	21	2.8	.1	---	---	650,695	33

APPENDIX IVa (cont.)

Summary of Data for Boulder Sewage Treatment Plant
June 16, 1971

Sample Location	Vol. Tol. Sol.		Fix Tol. Sol.		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	307	2560	328	2736	124	1034	98	817	27	225
Sec. Sl. Number 1	243	122	347	174	95	48	70	35	25	13
Sec. Sl. Number 2	224	112	317	159	48	24	38	19	11	6
Vac. Fil. Filtrate	1227	17	1174	17	765	11	462	7	304	4
Pri. # 1 Influent	289	1352	336	1572	127	594	115	538	25	117
Pri. # 2 Influent	342	1600	342	1600	136	636	105	491	31	145
Pri. # 1 Effluent	258	1205	233	1088	65	304	61	285	4	19
Pri. # 2 Effluent	206	962	325	1518	56	262	51	238	6	28
Tri. Fil. Influent	237	3420	276	3983	56	808	50	722	7	101
Tri. Fil. Recycle	252	1288	265	1354	49	250	40	204	9	46
Sec. # 1 Influent	252	1177	265	1238	49	229	40	187	9	42
Sec. # 2 Influent	252	1177	265	1238	49	229	40	187	9	42
Sec. # 1 Effluent	210	875	282	1175	21	88	17	71	3	13
Sec. # 2 Effluent	210	875	282	1175	21	88	17	71	3	13
Plant Effluent	134	1116	333	2774	---	---	---	---	---	---
Pri. Sl. Number 1	39,563	378	12,086	115	29,750	284	25,700	245	4025	38
Pri. Sl. Number 2	36,654	350	10,016	96	35,400	338	31,200	298	4200	40
Filter Feed	34,537	660	8,363	160	24,350	465	21,500	406	2800	59
Filter Cake	149,063	749	53,137	267	---	---	---	---	---	---
Grit	112,431	6	538,265	27	---	---	---	---	---	---

APPENDIX IVb

Summary of Data for Boulder Sewage Treatment Plant
June 24, 1971

Sample Location	BOD_5		COD		TKN		$PO_4^{=}$		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	169	1409	264	2202	15.8	132	15	125	729	6080
Sec. Sl. Number 1	59	25	145	60	17.2	7	14.7	6	764	317
Sec. Sl. Number 2	55	23	179	74	21.2	9	15	6	774	321
Vac.Fil. Filtrate	1077	9	1921	16	82	1	46	.5	2604	22
Pri. # 1 Influent	163	748	324	1486	17.6	87	14.7	67	806	3695
Pri. # 2 Influent	136	624	286	1312	16.3	75	14.7	67	704	3371
Pri. # 1 Effluent	135	619	293	1343	14.6	67	13.7	63	695	3185
Pri. # 2 Effluent	142	651	287	1315	15.9	73	14.7	67	703	3224
Tri.Fil. Influent	132	1575	251	2994	14.4	172	14.2	169	683	8148
Tri.Fil. Recycle	111	307	124	343	11.5	32	14.5	40	631	1746
Sec. # 1 Influent	111	509	124	568	11.5	53	14.5	67	631	2890
Sec. # 2 Influent	111	509	124	568	11.5	53	14.5	67	631	2890
Sec. # 1 Effluent	55	229	107	446	14	58	13.6	57	---	---
Sec. # 2 Effluent	63	263	120	500	13.9	58	13.1	55	585	2439
Plant Effluent	---	---	130	1084	13.8	115	13.1	109	620	5168
Pri. Sl. Number 1	25,950	154	69,500	411	2256	13	1120	7	53,780	318
Pri. Sl. Number 2	28,200	167	66,030	391	2203	13	940	6	55,275	327
Filter Feed	21,350	253	57,222	678	1392	17	1120	14	48,000	568
Filter Cake	---	---	700	502	29	21	19	14	178,570	718
Grit	---	---	660	11	20	.3	21	.4	336,900	17

APPENDIX IVb (cont.)

Summary of Data for Boulder Sewage Treatment Plant
June 24, 1971

Sample Location	Vol.Tol.S.		Fix. T. S.		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	287	2389	443	3695	121	1009	108	901	13	110
Sec. Sl. Number 1	256	106	508	211	75	31	60	25	15	6
Sec. Sl. Number 2	257	107	518	215	150	62	112	46	37	15
Vac.Fil. Filtrate	1375	11	1229	11	1150	10	714	6	435	4
Pri. # 1 Influent	237	1087	569	2610	116	530	99	454	17	76
Pri. # 2 Influent	282	1294	420	2064	130	596	118	544	18	83
Pri. # 1 Effluent	201	921	494	2264	65	299	59	269	7	30
Pri. # 2 Effluent	275	1260	429	1966	68	312	65	298	3	15
Tri.Fil. Influent	224	2672	460	5488	62	740	56	668	6	68
Tri.Fil Recycle	177	490	455	1260	45	125	37	103	9	24
Sec. # 1 Influent	177	811	455	2085	45	206	37	170	9	39
Sec. # 2 Influent	177	811	455	2085	45	206	37	170	9	39
Sec. # 1 Effluent	---	---	---	---	29	121	26	108	4	17
Sec. # 2 Effluent	134	559	451	1881	28	117	24	100	3	14
Plant Effluent	167	1388	453	3776	25	208	26	217	2	17
Pri. Sl. Number 1	40,408	239	13,372	79	43,438	257	36,070	214	7366	44
Pri. Sl. Number 2	40,645	241	14,629	87	44,719	265	36,964	219	7755	46
Filter Feed	37,783	447	10,218	121	34,200	405	28,900	342	5294	63
Filter Cake	126,475	509	52,059	209	---	---	---	---	---	---
Grit	168,228	9	168,670	9	---	---	---	---	---	---

APPENDIX Va

Summary of Data for Broomfield Sewage Treatment Plant
July 21, 1971

Sample Location	BOD_5		COD		TKN		$PO_4^{=}$		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	162	1350	325	2710	24	201	32	267	1064	8880
PostGrit Influent	162	1350	317	2640	24	201	30.4	254	1062	8860
Sec. Sl. Combined	134	462	153	527	15.6	54	37.6	130	1206	4150
Sec. Sl. Number 2	146	252	203	350	18.3	32	43.2	75	1195	2060
Tri.Fil. #1 Recyc	54	72	75	99	13.9	18	23.2	31	908	1202
Pri. # 1 Influent	172	1132	334	2200	27.4	181	39.6	261	1026	6750
Pri. # 2 Influent	146	962	250	1647	21.3	140	32	211	1033	6820
Pri. # 1 Effluent	88	553	150	943	18.4	116	22	138	868	5450
Pri. # 2 Effluent	71	448	141	890	16.7	105	23.2	147	891	5630
Tr.Fil#1 Influent	49	641	127	1661	17.7	232	28.4	372	893	11,680
Tr.Fil#1 Effluent	45	835	98	1820	14.9	277	27.2	505	874	16,200
Tr.Fil#2 Effluent	62	1150	76	1410	11.2	208	20.4	379	885	16,4[illegible]
Sec. # 1 Effluent	29	219	56	422	9.7	73	20.4	154	853	6430
Sec. # 2 Effluent	32	242	56	422	9.6	72	23.2	175	851	6410
Plant Effluent	34	282	56	460	9.8	81	23.2	192	851	7060
Tr.Fil#2 Recycle	34	231	56	377	9.8	66	23.2	157	851	5780
Pri. Sl. Number 1	50,200	1323	53,600	1413	1691	45	2520	66	49,025	1294
Pri. Sl. Number 2	57,970	1528	66,250	1746	2160	57	4120	108	59,450	1565
Decant Number 1	13,750	182	19,950	264	1092	14	1920	25	26,716	352
Dig. Sl. Number 1	25,569	338	55,000	726	2054	27	4700	62	67,830	895
Dig. Sl. Number2	---	---	---	---	---	---	---	---	---	---
Grit	---	---	276	14	3.8	.2	2.4	.1	383,500	19

APPENDIX Va (cont.)

Summary of Data for Broomfield Sewage Treatment Plant
July 21, 1971

Sample Location	Vol.Tol.Sol.		Fix.Tol.Sol.		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	310	2580	775	6460	250	2080	134	1118	117	976
PostGrit Influent	368	3065	694	5790	165	1375	134	1118	31	258
Sec. Sl. Combined	484	1665	722	2485	155	533	98	337	57	196
Sec. Sl. Number 2	429	740	766	1321	215	371	136	234	79	136
Tri.Fil. #1 Recyc	146	193	761	1007	46	60	34	45	12	16
Pri. # 1 Influent	373	2460	650	4280	256	1688	175	1152	80	530
Pri. # 2 Influent	298	1962	735	4840	184	1211	131	863	53	348
Pri. # 1 Effluent	133	836	735	4620	62	390	47	294	15	69
Pri. # 2 Effluent	214	1350	676	4270	52	328	40	250	13	79
Tr.Fil#1 Influent	208	2720	685	8960	56	735	43	566	13	168
Tr.Fil#1 Effluent	190	3520	684	12,700	55	1029	39	720	16	301
Tr.Fil#2 Effluent	192	3560	693	12,860	42	770	29	544	12	228
Sec. # 1 Effluent	182	1371	670	5050	12	91	10	75	2	17
Sec. # 2 Effluent	180	1358	672	5060	12	89	10	72	2	16
Plant Effluent	190	1575	662	5480	13	107	12	97	1	10
Tr.Fil#2 Recycle	190	1290	662	4500	13	88	12	80	1	8
Pri. Sl. Number 1	33,860	894	15,165	400	42,500	1121	31,100	820	11,500	303
Pri. Sl. Number 2	40,395	1062	19,055	502	45,700	1208	34,500	910	11,300	298
Decant Number 1	12,596	166	14,120	187	19,300	254	10,500	139	8800	116
Dig. Sl. Number 1	32,590	435	34,875	460	52,500	694	30,700	406	21,700	287
Dig. Sl. Number 2	---	---	---	---	---	---	---	---	---	---
Grit	221,000	11	162,500	8	---	---	---	---	---	---

APPENDIX Vb

Summary of Data for Broomfield Sewage Treatment Plant
July 29, 1971

Sample Location	BOD_5		COD		TKN		$PO_4^{=}$		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	180	1500	250	2085	24	200	23	192	1001	8350
PostGrit Influent	172	1433	239	1990	23.5	196	23.3	194	1060	8835
Sec. Sl. Combined	80	276	176	606	14.9	51	27.7	96	925	3185
Sec. Sl. Number 2	76	132	194	335	15.5	27	26.7	46	927	1600
Tri.Fil. #1 Recyc	44	58	62	82	16.6	22	22.7	30	866	1147
Pri. # 1 Influent	149	982	282	1859	26	171	---	---	1017	6700
Pri. # 2 Influent	134	884	168	1108	21.2	140	25.7	169	990	6520
Pri. # 1 Effluent	83	521	162	1018	22	138	26.7	168	921	5790
Pri. # 2 Effluent	89	562	113	714	19.4	122	24	152	999	6300
Tr.Fil#1 Influent	80	1048	143	1870	21.1	276	22.7	297	989	12,950
Tr.Fil#1 Effluent	45	835	89	1655	16.8	312	28	520	986	18,300
Tr.Fil#2 Effluent	50	928	56	1031	13.5	251	22	408	918	17,020
Sec. # 1 Effluent	36	272	49	367	13.1	99	24	181	972	7330
Sec. # 2 Effluent	33	251	49	367	12.5	94	19.3	146	959	7230
Plant Effluent	36	298	52	431	13.1	109	19.3	160	970	8040
Tr.Fil#2 Recycle	36	244	52	353	13.1	89	19.3	131	970	6580
Pri. Sl. Number 1	35,800	944	41,580	1100	1358	36	1800	47	42,361	1118
Pri. Sl. Number 2	36,900	973	51,755	1362	1755	46	3333	88	54,055	1425
Decant Number 1	7420	98	15,965	211	1098	15	1733	23	23,087	305
Dig. Sl. Number 1	---	---	---	---	---	---	---	---	---	---
Dig. Sl. Number 2	10,184		54,700		2395		5350		61,300	
Grit	---	---	---	---	---	---	---	---	---	---

APPENDIX Vb (cont.)

Summary of Data for Broomfield Sewage Treatment Plant
July 29. 1971

Sample Location	Vol.Tol.Sol.		Fix.Tol.Sol		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	330	2750	671	5600	159	1326	126	1050	33	275
PostGrit Influent	358	2985	702	5850	178	1480	145	1205	33	274
Sec. Sl. Combined	219	755	705	2430	56	194	42	143	15	51
Sec. Sl. Number 2	223	385	704	1213	61	106	45	77	17	29
Tri.Fil. #1 Recyl	211	280	655	868	32	43	28	37	4	5
Pri. # 1 Influent	215	1416	701	4615	196	1292	141	926	56	366
Pri. # 2 Influent	285	1878	698	4600	119	781	85	562	33	218
Pri. # 1 Effluent	260	1632	660	4150	74	462	55	348	18	114
Pri. # 2 Effluent	267	1685	732	4620	47	299	36	288	11	71
Tr.Fil#1 Influent	273	3575	716	9370	62	815	47	620	15	194
Tr.Fil#1 Effluent	297	5510	688	12,770	45	835	36	664	9	171
Tr.Fil#2 Effluent	261	4840	657	12,200	23	420	18	327	5	93
Sec. # 1 Effluent	299	2255	673	5070	16	119	7	49	9	70
Sec. # 2 Effluent	324	2440	635	4790	16	117	7	54	8	64
Plant Effluent	278	2310	691	5725	18	147	8	69	10	79
Tr.Fil#2 Recycle	278	1888	691	4700	18	121	8	56	10	65
Pri. Sl. Number 1	29,503	777	12,868	339	27,000	712	22,300	588	4700	124
Pri. Sl. Number 2	35,374	932	19,691	519	32,900	867	26,400	696	6500	171
Decant Number 1	11,418	151	11,669	154	11,200	148	8400	111	2800	36
Dig. Sl. Number 1	---	---	---	---	---	---	---	---	---	---
Dig. Sl. Number 2	31,369		29,931		56,400		30,900		20,500	
Grit	---	---	---	---	---	---	---	---	---	---

APPENDIX VI. Summary of Data for Baker on Aug. 23, 1971

Sample Location	BOD_5		COD		TKN		$PO_4^{=}$		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	209	1743	372	3100	27	225	37.3	311	1224	10,208
PostGrit Influent	243	2027	387	3220	27.6	230	34	284	1235	10,300
Sec. Sl. Recycle	252	277	488	537	50.4	55	53.3	58	1624	1786
Digester Decant	9750	166	37,200	632	2995	51	2267	39	33,589	571
Primary Influent	243	2294	398	3755	28.3	267	38.7	365	1255	11,847
Primary Effluent	95	893	259	2435	26.7	251	38.7	364	1234	11,600
Tri.Fil. Influent	142	2394	171	2885	24.7	416	34.7	585	1200	20,232
Tri.Fil. Effluent	70	658	123	1156	22.4	211	30	282	1226	11,524
Tri.Fil. Recycle	70	496	123	871	22.4	159	30	212	1226	8680
Second. Effluent	71	591	108	900	20.7	34	34.7	282	1162	9679
Primary Sludge	50,100	2054	71,392	2925	2145	88	1933	79	61,829	2535
Grit	---	---	100		2.3		9.6		606,683	

Summary of Data for Baker on Aug. 27, 1971

Sample Location	BOD_5 mg/L	BOD_5 LB.	COD mg/L	COD LB.	TKN mg/L	TKN LB.	$PO_4^{=}$ mg/L	$PO_4^{=}$ LB.	Total Solids mg/L	Total Solids LB.
Plant Influent	148	1234	336	2802	26.6	222	31	259	1349	11,246
PostGrit Influent	140	1168	338	2819	26.4	220	31.5	263	1384	11,543
Sec. Sl. Recycle	344	378	587	646	52.4	58	58	64	1762	1938
Digester Decant	4660	79	16,200	275	1400	24	834	14	26,185	445
Primary Influent	169	1600	352	3333	27.1	256	33	257	1393	13,187
Primary Effluent	132	1245	233	2197	25.7	243	27.5	259	1229	11,589
Tri.Fil. Influent	100	1686	166	2799	22.9	386	27	455	1267	21,362
Tri.Fil. Effluent	80	754	145	1367	21.2	200	28.5	269	1249	11778
Tri.Fil. Recycle	80	602	145	1092	21.2	160	28.5	215	1249	9405
Second. Effluent	37	308	82	682	20.1	167	24.5	204	1152	9585
Primary Sludge	29,000	1189	69,622	2855	2110	87	2034	83	58,817	2411
Digested Sludge										

APPENDIX VI. (cont.) Summary of Data for Baker on Aug. 23, 1971										
Sample Location	Vol.Tol.Sol.		Fix.Tol.Sol		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	360	3002	864	7206	152	1268	127	1059	25	209
PostGrit Influent	362	3019	873	7281	155	1293	132	1101	22	183
Sec. Sl. Recycle	506	556	1117	1229	467	514	332	365	135	149
Digester Decant	21,747	370	11,842	201	26,800	456	15,900	270	10,900	185
Primary Influent	357	3370	898	8500	172	1624	144	1359	28	264
Primary Effluent	295	2773	939	8827	93	874	77	724	16	150
Tri.Fil. Influent	249	4198	951	16,034	110	1855	72	1214	38	641
Tri.Fil. Effluent	238	2237	988	9287	96	902	66	620	30	282
Tri.Fil. Recycle	238	1685	988	6995	96	680	66	467	30	212
Second. Effluent	217	1808	944	7864	90	666	62	516	32	267
Primary Sludge	45,688	1873	16,141	662	45,900	1882	33,200	1361	12,700	521
Grit	33,448	---	633,234		---	---	---	---	---	---
Summary of Data for Baker on Aug. 27, 1971										
Plant Influent	423	3528	925	7715	156	1301	130	1084	26	217
PostGrit Influent	434	3620	947	7898	164	1368	138	1151	25	209
Sec. Sl. Recycle	576	634	1186	1305	488	537	381	419	107	118
Digester Decant	19,799	337	6386	109	11,600	197	8800	150	2800	48
Primary Influent	380	3599	1013	9593	173	1638	142	1345	31	294
Primary Effluent	234	2206	995	9383	85	802	70	660	15	141
Tri.Fil. Influent	313	5277	955	16,093	68	1146	52	877	15	253
Tri.Fil. Effluent	307	2895	942	8883	69	651	53	500	15	141
Tri.Fil. Recycle	307	2312	942	7093	69	520	53	399	15	113
Second. Effluent	223	1855	929	7729	31	258	26	216	5	42
Primary Sludge	44,593	1828	14,224	583	49,700	2038	41,700	1710	8000	328
Digested Sludge										

APPENDIX VII.

Summary of Data for Colorado Springs on Oct. 28, 1971

Sample Location	BOD_5		COD		TKN		PO_4		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	225	1877	442	3686	28.2	235	30.5	254	647	5396
Primary Influent	273	3083	538	6070	31.7	340	39	440	861	9718
Primary Effluent	193	2173	291	3272	28	315	33.5	377	682	7679
Plant Effluent	99	826	191	1590	24.4	204	34.5	288	590	4921
Porteous Feed	19,550	695	50,600	1799	1543	55	1650	59	36,180	1287
Porteous Effluent	16,600	719	39,534	1713	1281	56	1033	45	30,746	1320
HoldTank Decant	3203	181	6256	353	268	15	158	9	5053	285
Vac.Fil. Feed	30,270	495	82,168	1343	1576	26	2117	35	64,961	1061
Vac.Fil. Filtrate	2620	40	5245	81	173	3	187	3	4203	65
Vac.Fil. Cake	---	---	1215	1094	11.9	11	45.6	41	345,015	901
	Vol.Tol.Sol.		Fix.Tol.Sol.		Sus. Sol.		V. S. S.		F. S. S.	
Plant Influent	343	2861	304	2535	171	1426	131	1093	40	334
Primary Influent	482	5444	379	4280	242	2733	199	2248	43	486
Primary Effluent	232	2612	449	5055	99	1115	79	889	20	225
Plant Effluent	158	1318	429	3578	60	500	51	425	9	75
Porteous Feed	28,071	998	8109	288	31,000	1102	26,800	953	4200	149
Porteous Effluent	24,270	1051	6610	286	23,600	1022	19,100	827	4500	195
HoldTank Decant	3908	221	1145	65	1445	82	1165	66	280	16
Vac.Fil. Feed	45,548	744	19,413	317	60,000	980	44,600	729	15,400	252
Vac.Fil. Filtrate	2833	44	1370	21	1885	29	1250	19	635	10
Vac.Fil. Cake	236,327	617	109,468	284	---	---	---	---	---	---

APPENDIX VIIIa

Summary of Data for Aspen Metro Sewage Treatment Plant
August 11-12, 1971

Sample Location	BOD_5		COD		TKN		$PO_4^=$		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
PostGrit Influent	250	2085	526	4387	26.2	219	27	225	706	5888
Act. Sl. Recycle	3156	19,220	9480	57,733	577	3514	505	3075	11,863	72,246
Tank # 1 Influent	1564	11,344	4990	36,193	285	2067	175	1269	6040	43,809
Tank # 2 Influent	2737	19,852	4608	33,422	290	2103	230	1668	6289	45,579
Start of Tank # 1	1465	10,626	5640	40,908	272	1973	230	1668	5787	41,974
Start of Tank # 2	1450	10,517	5396	39,138	267	1937	210	1523	5658	41,038
1/2 of Tank # 1	1515	10,989	5330	38,659	267	1937	225	1632	5878	42,634
1/2 of Tank # 2	1450	10,517	5530	40,110	273	1980	210	1523	5883	42,670
Tank # 1 Effluent	1437	10,423	5850	42,431	272	1973	200	1451	5778	41,909
Tank # 2 Effluent	1525	11,061	5610	40,690	268	1944	260	1886	6066	43,998
Second. Influent	1609	23,331	6125	88,813	318	4611	250	3625	6658	96,451
Second. Effluent	50	408	95	773	13.5	110	13.6	111	530	4325
Waste Act. Sl.	3156	502	9480	1509	577	92	505	80	11,863	1889
Plant Effluent	10	82	47	381	15	122	23.2	189	456	3721
Grit	---	---	---	---	---	---	---	---	---	---

APPENDIX VIIIa (cont.)

Summary of Data for Aspen Metro Sewage Treatment Plant
August 11-12, 1971

Sample Location	Vol.Tol.Sol.		Fix.Tol.Sol.		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
PostGrit Influent	442	3686	264	2202	351	2927	309	2577	42	350
Act. Sl. Recycle	7906	48,148	3957	24,098	10,815	65,863	7595	46,254	3220	19,610
Tank # 1 Influent	4011	29,092	2028	14,709	5619	40,755	3914	28,389	1705	12,367
Tank # 2 Influent	4166	30,217	2117	15,355	6000	43,519	4149	30,093	1851	13,426
Start of Tank # 1	3761	27,279	2026	14,695	5071	36,781	3484	25,270	1587	11,510
Start of Tank # 2	3649	26,467	2010	14,579	5334	38,688	3669	26,612	1665	12,076
1/2 of Tank # 1	3827	27,757	2052	14,883	5612	40,704	3860	27,997	1752	12,707
1/2 of Tank # 2	3874	28,099	2009	14,572	5371	38,957	3667	26,597	1704	12,359
Tank # 1 Effluent	3766	27,315	2012	14,593	5673	41,147	3950	28,650	1723	12,497
Tank # 2 Effluent	4038	29,288	2028	14,709	5494	39,848	3790	27,489	1704	12,359
Second. Influent	4430	64,235	2228	32,306	6105	88,523	4210	61,045	1895	27,478
Second. Effluent	246	2007	283	2309	58	473	39	318	18	147
Waste Act. Sl.	7906	1259	3957	630	10,815	1722	7595	1209	3220	513
Plant Effluent	187	1526	270	2203	8	65	5	41	3	25
Grit	---	---	---	---	---	---	---	---	---	---

APPENDIX VIIIb

Summary of Data for Aspen Metro Sewage Treatment Plant
August 17-18, 1971

Sample Location	BOD_5		COD		TKN		$PO_4^=$		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
PostGrit Influent	133	1109	242	2018	19.1	159	21.3	178	666	5554
Act. Sl. Recycle	3080	19,004	7732	47,706	518	3196	495	3054	9580	59,109
Tank # 1 Influent	2138	15,287	8418	60,189	283	2023	302	2159	5257	37,586
Tank # 2 Influent	2183	15,608	9692	69,298	267	1909	215	1537	5012	35,836
Start of Tank # 1	1902	13,599	8389	59,981	224	1602	180	1287	4371	31,253
Start of Tank # 2	1740	12,441	9526	68,111	232	1659	205	1466	4331	30,967
1/2 of Tank # 1	2230	15,945	8712	62,291	231	1652	315	2252	4318	30,874
1/2 of Tank # 2	2387	17,067	7683	54,933	211	1509	340	2431	4404	31,487
Tank # 1 Effluent	2584	18,476	8497	60,754	230	1645	225	1609	4291	30,681
Tank # 2 Effluent	2192	15,673	8308	60,117	226	1616	210	1502	4381	31,324
Second. Influent	2033	29,072	8673	124,024	262	3747	245	3504	4825	68,998
Second. Effluent	40	330	61	504	12	99	16.6	137	425	3511
Waste Act. Sl.	3080	239	7732	599	518	40	495	38	9580	742
Plant Effluent	16	132	31	256	11.6	96	15	124	384	3172
Grit	---	---	923		4		24		55,547	

APPENDIX VIIIb (cont.)

Summary of Data for Aspen Metro Sewage Treatment Plant
August 17-18, 1971

Sample Location	Vol. T. S.		Fix. T. S.		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
PostGrit Influent	326	2719	340	2836	135	1126	112	934	23	192
Act. Sl. Recyele	6716	41,438	2763	17,048	8830	54,481	6460	39,858	2370	14,623
Tank # 1 Influent	3682	26,326	1575	11,261	4655	33,283	3380	24,167	1275	9116
Tank # 2 Influent	3467	24,775	1546	11,054	3798	27,156	2743	19,612	1055	7543
Start of Tank # 1	3032	21,679	1339	9574	3585	25,633	2565	18,340	1020	7293
Start of Tank # 2	2885	20,628	1446	10,339	3575	25,561	2565	18,340	1010	7222
1/2 of Tank # 1	2883	20,613	1435	10,260	3935	28,135	2843	20,327	1093	7815
1/2 of Tank # 2	2952	21,107	1450	10,368	4028	28,800	2948	21,078	1080	7722
Tank # 1 Effluent	2883	20,613	1407	10,060	3738	26,727	2648	18,933	1090	7794
Tank # 2 Effluent	2933	20,971	1448	10,353	3725	26,634	2668	19,076	1058	7565
Second. Influent	2282	32,633	1543	22,065	4473	63,964	3303	47,233	1170	16,731
Second. Effluent	144	1189	281	2321	51	421	37	306	13	107
Waste Act. Sl.	6716	520	2763	214	8830	685	6460	501	2370	184
Plant Effluent	118	975	266	2197	3.5	29	2.5	21	1	8
Grit	9743		45,804		---	---	---	---	---	---

APPENDIX IX.

Sample Location	BOD_5		COD		TKN		$PO_4^=$		Total Solids	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Summary of Data for Snowmass-at-Aspen on August 11-12, 1971										
Plant Influent	105	876	211	1760	19.3	161	22.7	189	522	4353
Aer. Tank Influent	128	1068	250	2085	19.1	159	20.3	169	499	4162
Act. Sl. Recycle	3470	78,040	5555	124,932	334	7512	340	7647	8604	193,504
Start of Aer. Tank	1833	56,517	4980	153,548	223	6876	260	8017	6169	190,208
1/3 of Aer. Tank	4141	127,679	5130	158,173	240	7400	210	6475	6223	191,874
2/3 of Aer. Tank	4404	135,789	5000	154,165	225	6937	260	8017	6096	187,957
Aer. Tank Effluent	4542	139,488	4960	152,932	237	7307	270	8325	6230	192,090
Sec. # 1 Effluent	34	142	37	153	2.7	11	13.8	58	303	1264
Sec. # 2 Effluent	8	33	20	85	1.8	7	14.2	59	350	1460
Plant Effluent	18	150	52	431	3.2	27	8	67	418	3486
Grit	---	---	705	9	20	.3	8	.1	29,516	12
Summary of Data for Snowmass-at-Aspen on August 17-18, 1971										
Plant Influent	124	1034	253	2110	20.2	168	18.3	153	496	4137
Aer. Tank Influent	185	1543	284	2369	22.2	185	18.7	156	565	4712
Act. Sl. Recycle	4985	29,312	6046	35,550	487	2864	505	2969	11,560	67,973
Start of Aer. Tank	5300	75,366	7272	103,408	212	3008	213	3022	5215	74,157
1/3 of Aer. Tank	5351	76,091	7056	100,336	185	2624	188	2666	4950	70,389
2/3 of Aer. Tank	5390	76,646	6615	94,065	195	2773	230	3271	4815	68,469
Aer. Tank Effluent	5250	74,513	7507	106,750	193	2744	220	3128	5132	72,977
Sec. # 1 Effluent	90	375	104	434	9.3	39	22.4	93	392	1635
Sec. # 2 Effluent	100	417	153	638	12.4	52	25	104	541	2256
Plant Effluent	30	250	57	475	4	33	7.4	62	258	2152
Grit	---	---	161	1	5	0	9	.1	60,895	7

APPENDIX IX. (cont.)

Summary of Data for Snowmass-at-Aspen on August 11-12, 1971

Sample Location	Vol. T. S.		Fix. T. S.		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	313	2610	209	1743	131	1093	101	842	29	242
Aer.Tank Influent	271	2260	228	1902	182	1518	121	1009	60	500
Act. Sl. Recycle	4582	103,049	4022	90,455	8030	180,595	4295	96,595	3735	84,000
Start of Aer.Tank	3358	103,537	2811	86,672	5708	175,995	3126	96,384	2582	79,611
1/3 of Aer.Tank	3390	104,524	2833	87,350	5616	173,158	3045	93,886	2571	79,272
2/3 of Aer.Tank	3278	101,071	2818	86,887	5563	171,524	2977	91,790	2586	79,734
Aer.Tank Effluent	3367	103,815	2862	88,244	5861	180,712	3159	97,401	2702	83,311
Sec. # 1 Effluent	143	596	160	667	31	129	21	88	10	42
Sec. # 2 Effluent	195	813	155	646	11	46	9	38	2	8
Plant Effluent	183	1526	234	1952	38	317	22	183	16	133
Grit	21,801	9	7714	3	---	---	---	---	---	---

Summary of Data for Snowmass-at-Aspen on August 17-18, 1971

Sample Location	Vol. T. S.		Fix. T. S.		Sus. Sol.		V. S. S.		F. S. S.	
	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
Plant Influent	259	2160	237	1977	153	1276	95	792	58	484
Aer.Tank Influent	304	2535	260	2168	208	1735	135	1126	72	600
Act. Sl. Recycle	6296	37,020	5264	30,952	10,705	62,945	6080	35,750	4655	27,371
Start of Aer.Tank	2839	40,371	2375	33,773	4802	68,284	2735	38,892	2068	29,407
1/3 of Aer.Tank	2645	37,612	2305	32,777	4462	63,450	2562	36,432	1900	27,018
2/3 of Aer.Tank	2555	36,332	2259	32,123	4380	62,284	2405	34,199	1975	28,085
Aer.Tank Effluent	2786	39,617	2346	33,360	4583	65,170	2485	35,337	2097	29,819
Sec. # 1 Effluent	154	642	238	992	150	626	68	284	81	338
Sec. # 2 Effluent	241	1005	300	1251	289	1205	164	684	127	530
Plant Effluent	102	851	156	1301	42	350	28	234	14	117
Grit	10,042	1	50,852	6	---	---	---	---	---	---

APPENDIX X. Summary of Data for Metro Denver Sewage Treatment Plant

Sample	BOD		COD		TKN		PO4		Total Solids	
Location	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
ClearCk. Influent	191	273	453	648	27	38.6	29.5	42	1371	1961
Sand Ck. Influent	195	156	377	301	27	21.5	30.5	24	1247	995
Package Plant	---	---	1044	41	9.1	.4	3.5	.1	2264	89
Pre-Grit Influent	235	536	475	1083	33.5	76	34	78	1367	3181
Primary Influent	180	411	362	826	28.9	66	28.5	65	1217	2776
Primary Effluent	130	296	250	569	25.6	58	28	64	1187	2699
Den. N.S. Effluent	143	868	248	1506	22.6	137	22	134	908	5513
Settled Applied	149	1246	215	1802	25.2	211	24.5	205	1082	9069
N. Tank Effluent	1100	7009	3305	21,059	204	1300	235	1497	3235	20,613
S. Tank Effluent	1390	8857	3516	22,404	225	1434	263	1676	3651	23,264
Second. Effluent	29	242	86	717	18.1	151	20.5	171	859	7164
Plant Effluent	21	175	77	642	17.9	149	15.5	129	840	7006
North R.A.S.	3955	8622	10,548	22,995	616	1343	670	1461	9325	20,329
South R.A.S.	4000	8720	8185	17,843	541	1179	740	1613	7832	17,074
Waste Act. Sl.	---	---	10,108	526	616	32	830	43	10,915	496
Aer.Dig. Supernat	---	---	658	3.5	46	.2	82	.4	1864	10
Concent. Feed	940	44	8076	376	457	21	845	39	8435	393
Concent. Float	33,650	249	47,062	348	2729	20	4300	32	42,577	315
Concent. Subnat.	---	---	135	5	14	.5	184	7	1347	53
Primary Sludge	29,019	194	107,675	718	2449	16	2700	18	76,709	513
Den.Dig. Sludge	5893	28	40,836	194	2145	10	1600	7.6	41,451	197
Vac.Fil. Feed	---	---	53,470	989	2182	40	2750	51	48,937	905
Vac.Fil. Cake	---	---	709	970	32	43	15	20	169,400	230
Vac.Fil. Filtrate	2194	24	5091	55	437	5	148	1.6	10,804	117
Filtrate I.P.W.	1600	21	4148	54	301	4	142	1.8	9150	118
Grit	---	---	111		2.4		22		713,042	

APPENDIX X. (cont.) Summary of Data for Metro Denver										
Sample	Vol. T. S.		Fix. T. S.		Sus. Sol.		V. S. S.		F. S. S.	
Location	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.	mg/L	LB.
ClearCk. Influent	445	636	926	1324	209	299	167	239	40	57
Sand Ck. Influent	369	294	878	701	191	152	157	125	34	27
Package Plant	937	37	1327	54	354	14	211	8	143	6
Pre-Grit Influent	412	940	955	2178	291	664	218	497	73	167
Primary Influent	323	737	894	2039	165	376	124	283	41	94
Primary Effluent	286	650	901	2049	75	171	57	130	18	41
Den.N.S. Effluent	229	1390	680	4129	91	553	82	498	9	55
Settled Applied	382	3202	700	5867	113	947	92	771	21	176
N. Tank Effluent	2051	13,069	1184	7544	2472	15,752	1918	12,221	558	3556
S. Tank Effluent	2343	14,930	1310	8347	2703	17,223	2090	13,317	613	3906
Second. Effluent	184	1535	675	5630	47	392	35	292	12	100
Plant Effluent	163	1359	678	5655	41	342	32	267	9	75
North R.A.S.	7324	15,966	2002	4364	7410	16,154	5770	12,579	1645	3586
South R.A.S.	5366	11,698	2467	5378	5930	12,927	4810	10,486	1125	2453
Waste Act. Sl.	8395	376	2520	121	8210	427	6610	344	1600	83
Aer.Dig. Supernat	830	4.5	1034	6	416	2	306	2	111	1
Concent. Feed	5774	269	2661	124	4640	216	3500	163	1140	53
Concent. Float	27,191	201	15,385	114	33,600	249	26,700	198	6900	51
Concent. Subnat.	427	17	920	36	68	3	60	2	8	1
Primary Sludge	54,168	361	22,544	150	58,900	393	43,700	291	15,200	101
Den.Dig. Sludge	20,116	96	22,353	106	33,600	160	20,100	95	13,500	64
Vac.Fil. Feed	35,766	662	13,171	243	37,400	692	28,200	522	9200	170
Vac.Fil. Cake	78,915	108	90,485	130	---	---	---	---	---	---
Vac.Fil. Filtrate	3683	40	7121	77	3165	34	1568	17	1598	17
Filtrate I.P.W.	3880	50	5275	68	831	11	424	5	407	5
Grit	80,264		632,780		---	---	---	---	---	---

Thesis
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Macroscopic analysis of wastewater treatment plants and its application.